(2)

Report No. NADC-92088-60

THE EFFECTS OF DISPLAY AND RESPONSE CODES ON INFORMATION PROCESSING IN AN IDENTIFICATION TASK

Jeffrey G. Morrison, Ph.D.
Air Vehicle and Crew Systems Technology Department (Code 6021)
NAVAL AIR WARFARE CENTER
AIRCRAFT DIVISION WARMINSTER
P.O. Box 5152
Warminster, PA 18974-0591

23 SEPTEMBER 1992

FINAL REPORT

Approved for Public Release, Distribution is Unlimited

Prepared for:
Air Vehicle and Crew Systems Technology Department (Code 6021)
NAVAL AIR WARFARE CENTER
AIRCRAFT DIVISION WARMINSTER
P.O. Box 5152
Warminster, PA 18974-0591

NOTICES

REPORT NUMBERING SYSTEM — The numbering of technical project reports issued by the Naval Air Warfare Center, Aircraft Division, Warminster is arranged for specific identification purposes. Each number consists of the Center acronym, the calendar year in which the number was assigned, the sequence number of the report within the specific calendar year, and the official 2-digit correspondence code of the Functional Department responsible for the report. For example: Report No. NAWCADWAR-92001-60 indicates the first Center report for the year 1992 and prepared by the Air Vehicle and Crew Systems Technology Department. The numerical codes are as follows:

CODE	OFFICE OR DEPARTMENT
00	Commanding Officer, NAWCADWAR
01	Technical Director, NAWCADWAR
05	Computer Department
10	AntiSubmarine Warfare Systems Department
20	Tactical Air Systems Department
30	Warfare Systems Analysis Department
50	Mission Avionics Technology Department
60	Air Vehicle & Crew Systems Technology Department
70	Systems & Software Technology Department
80	Engineering Support Group
90	Test & Evaluation Group

PRODUCT ENDORSEMENT — The discussion or instructions concerning commercial products herein do not constitute an endorsement by the Government nor do they convey or imply the license or right to use such products.

Reviewed By: J. K. Schmitt — Date: 5 NOV 92
Branch Head LCDR MSC USN

Reviewed By: A M Mitchell — Date: 5 NOV 92
Division Head

Reviewed By: [signature] — Date: 6 Nov. 92
Director/Deputy Director

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	23 September 1992	FINAL REPORT

4. TITLE AND SUBTITLE

The Effects of Display and Response Codes on Information Processing in an Identification Task.

5. FUNDING NUMBERS

(None)

6. AUTHOR(S)

Jeffrey G. Morrison, Ph.D.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Naval Air Warfare Center
Aircraft Division - Warminster
P.O. Box 5152
Warminster, PA 18974-0591

8. PERFORMING ORGANIZATION REPORT NUMBER

NAWCADWAR-92088-60

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

(None)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

(None)

11. SUPPLEMENTARY NOTES

Report completed as author's Doctoral Thesis while attending Georgia Institute of Technology, Dr. Gregory M. Corso, Chair. Thesis accepted by School of Psychology 23 September 1992.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Four experiments are reported that employ the Within-Task Subtractive (WiTS) method for partitioning response time. The assumptions and advantages of this methodology are discussed relative to subtractive and additive factors methodology. Code and coding issues such as the particular target-task combination used,response mapping, target density, and blocks were manipulated. Study 1 showed that digits were processed differently from letters in terms of input and output processing. Study 2 showed that the identification of different categories of codes in the presence of noise codes generated different effects on input and output processing. Study 3 examined the identification of codes from multiple code categories when there is a single code per target versus when there are multiple codes per target. The results show that while there are differences in input processing depending on the location of codes, when the results are considered on a per-code basis, the differences in input are accounted for by the different number of visual fixations required, rather than differences in processing. Study 4 examined the effects of identifying redundant codes. Redundant codes were processed as separate codes early in practice, and processed as a single, composite code late in practice during input, and were output

14. SUBJECT TERMS

Response Time, Reaction Time, Human Information Processing, Codes, Symbology, Coding, Digits, Letters, Redundant, Response Mapping, Keyboards, Human Factors, Cognition, Input, Output

15. NUMBER OF PAGES

356

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

13. ABSTRACT (Continued)

much faster than relevant, non-redundant codes in output.

Studies 1-3 also examined the impact of response mapping. Two response mappings were developed based on schemas common in computer and aircraft applications. One had a single response code assigned to each key, while the other had multiple codes assigned to each key. It was expected that the response mapping would only affect output processing, however there were a number of subtle interaction effects for input processing. It was concluded that the output side of the task affects the way information is input in memory.

A variety of principles and guidelines are proposed. Future research directions and specific studies are discussed. An "iterative cascade model" is proposed to account for the findings.

ACKNOWLEDGEMENTS

This document represents the culmination of almost three years of effort. Because the work extended over such a long period of time, there is a very large number of people whom I need to acknowledge. First, I would like to extend my gratitude to friends and colleagues at the Naval Air Warfare Center - Aircraft Division, Warminster, Pennsylvania, who provided moral support, tolerated my frequent frustration and resultant moodiness. It would never have been possible to complete this document if I had not been able to rely on the patience of these people, and their competence and willingness to cover for my extended absences while this document was being prepared. In particular, I must acknowledge the efforts of Dr. Jonathan Gluckman, and my branch heads: LCDR John Schmidt, and CDR John Deaton. Dr. Joel Warm, a visiting professor from the University of Cincinnati also has my sincere gratitude for taking time during his visit to NAWC to provide invaluable wisdom and editorial consultation.

I must also recognize the efforts and patience of my doctoral committee at the Georgia Institute of Technology. I am particularly indebted to my friend, mentor, and chair person Dr. Gregory Corso. When I think back on all the ways Dr. Corso has influenced not only the research described in this document, but my personal and professional development as well, I realize how truly lucky I have been to have him as a mentor. I am privileged to be considered a colleague. Again, my heartfelt gratitude and appreciation, and best wishes in future endeavors.

I would also like to express my appreciation and encouragement of my fellow students and commiseraters at the Georgia Institute of Technology. I would particularly like to thank Frederick Rudolph for his frequent consultations, and for providing me access to his thesis data. For Frederick, Katherine Berkovsky, Kevin Hodge, and all my co-sufferers still at Georgia Tech., I offer two lessons learned: 1) Get the dissertation finished as quickly as possible, you've earned the rewards that come with it and it is worth it; and 2) Don't try to write a book for a dissertation - the copying costs alone will kill you!

Finally, I would like to express my love and gratitude to my family. Were it not for their love, patience, encouragement, not to mention occasional financial support over the years, I would never have gotten this far in my education. Thank you all.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

a	-	constant for encoding in the Sternberg (1969) & Briggs (1974) CRT models; *or* accumulator function in the Teichner & Williams (1977) CRT model.
a_{D+R}	-	Display and response code accumulator in the iterative cascade model.
a_k	-	Accumulator constant associated with arousal properties of stimulus in teichner & Williams (1977) processing model.
a_R	-	Response mapping accumulator in the iterative cascade model.
a_s	-	Accumulator constant associated with neural transmission speed in Teichner & Williams (1977) model.
b	-	Constant for rate of central processing in the Sternberg (1969) & Briggs (1974) processing models.
CRT	-	Choice Reaction Time.
F	-	F Ratio from ANOVA.
f_x	-	Empirically determined constants in Teichner & Williams (1977) CRT model.
H_C	-	Amount of information in central processing in Briggs (1974) CRT model.
M	-	Memory set size in Sternberg (1969) CRT model.
MANOVA	-	Multivariate Analysis of Variance.
MHz	-	Mega-Hertz.
msec.	-	milliseconds.
MS-DOS	-	MicroSoft Disk Operating System.
p	-	probability of rejecting null hypothesis when it should be accepted.
P	-	Performance measure from the Teichner & Williams (1977) CRT model.
R	-	A series of Responses output in the iterative cascade processing model.

R-Ex - Response Execution processing in Teichner & Williams (1977) processing model.

R-Sel - Response Selection processing in Teichner & Williams (1977) processing model.

RT - Reaction Time in Sternberg (1969) CRT model; *or* simple reaction time in Teichner & Williams (1977) processing model.

S - A series of Sensory Inputs in iterative cascade processing model.

S-C-R - Stimulus-Cognition-Response.

S-R - Stimulus-Response.

$T_{S\text{-}S}$ - Stimulus-Stimulus Translation in Teichner & Williams (1977) model.

$T_{S\text{-}R}$ - Stimulus-Response Translation in Teichner & Williams (1977) model.

VGA - Very high resolution Graphics Adapter.

WiTS - Within-Task Subtractive.

ABSTRACT

The Effects of Display and Response Codes on Information Processing in an Identification Task.

Jeffrey Glenn Morrison

356 pages

Directed by Dr. G. M. Corso

Four experiments are reported that employ the Within-Task Subtractive (WiTS) method for partitioning response time. The assumptions and advantages of this methodology are discussed relative to subtractive and additive factors methodology. Symbology and coding issues such as the particular target-task combination used, response mapping, target density and blocks of practice were manipulated. Study 1 showed that digits and letters are processed differently from each other in terms of input and output processing. Study 2 showed that the identification of different categories of codes in the presence of noise codes generated different effects on input and output processing. Study 3 examined the identification of codes from multiple code categories when there is a single code per target versus when there are multiple codes per target. The results show that while there are differences in input processing depending on the location of codes, when the results are considered on a per-code basis, the differences in input are accounted for by the different number of visual fixations required, rather than differences in processing. A fourth study examined the effects of identifying redundant codes. Redundant codes were processed as separate codes early in practice, and processed as a single, composite code late in practice during input, and were output much faster than relevant, non-redundant codes in output.

Studies 1-3 also examined the impact of response mapping. Two response mappings were developed based on schemas common in computer and aircraft applications. One had a single response code assigned to each key, while the other had multiple codes assigned to each key. It was expected that the response mapping would only affect output processing, however there were a number of subtle interaction effects for input processing. It was concluded that the output side of the task affects the way information is input in memory.

A variety of principles and guidelines are proposed. Future research directions and specific studies are discussed. An "iterative cascade model" is proposed to account for the findings.

CHAPTER 1 - Introduction.

Humans interact with their environment by taking information from the environment, performing some cognitive activity regarding the implications of what they perceive, and then acting to affect some change in the environment. While this is a relatively simple explanation of how information in the world affects behavior, the reality is that despite over a century of study, we still have a very poor understanding of how people process information, or what aspects of the environment may impact how that information is processed. This paper will study two aspects of this problem.

First, the use of different symbols and how they are arranged on a display are examined in terms of how they affect human performance in an information processing task. For the purposes of this paper, a code is defined as the explicit information associated with a particular symbol in a coding scheme. For example, the designer of a display may employ the symbols: 0, 1, 2, 3, and 4. In the context of a specific information processing task, the designer may assign different meanings to each of the symbols in the set. When a user of the display sees the symbol, (or hears its name spoken aloud), the symbol serves as a signal to the user that he/she is to emit a specific response or responses. When the user of the display emits the desired response(s), it can be said that information has been transmitted (e.g. Shannon and Weaver, 1949). Based on his/her understanding of the task demands, information has been transmitted from the display in the task to the user, as well as from the user to some other component of the system in the form of an elicited response (Teichner, 1977).

The second aspect of how performance in an information processing task may be affected by codes relates to how the response side of the task affects the way codes are read from a display and processed. A common design feature of many person-machine interfaces is the use of multi-function keyboards. Multi-function keyboards differ from single-function keyboards in that a single-function keyboard has a single response code (or function) assigned to each response key. This is also typical of how codes are assigned in most studies of information processing and human performance. Multi-function keyboards are characterized by having several different response codes (or functions) assigned to the same response key. Such a mapping has several advantages in that there are fewer keys required to perform the task, however there may be a cost in terms of the perceived complexity of the response panel mapping. There is little data that describes how these two approaches to the assignment of response codes to response keys affect the way information is processed in general, and the way information is read from a display and encoded into memory in particular. The research described in this report attempts to address this issue.

A third thrust of this research is to consider the nature of the tools available to the psychologist to study codes, coding, and the nature of information processing. To a very large degree, we cannot directly study the physical mechanisms that generate the behaviors of interest. As a result, the study of processing typically depends on measuring behavior in terms of the time and/or accuracy required to perform a task under a variety of theoretically interesting conditions. The nature of information processing is then inferred from the nature of changes in the time and/or accuracy measures seen in the different experimental conditions. This report will describe and demonstrate an alternative procedure for interpreting response time than is typically found in the experimental literature. The method, developed by Warren H. Teichner (1977, 1978), has seen little exposure in the literature due to Dr. Teichner's death shortly after it was developed. Therefore, a considerable part of this paper describes the methodology, and its merits relative to more traditional methods for partitioning response time.

Alternative approaches to the partitioning of response time and their utility in making inferences about information processing are addressed in Chapter 2. The remainder of this Chapter will survey the experimental psychology literature to assess what has been learned with regard to codes and coding, as well as how the response side of the task might impact information processing. The survey focuses on a variety of issues related to how code symbols are used. One such issue is whether the use of different symbol sets, such as in different code categories have an impact on information processing. The review of code categories focuses on digits and letters because they are often used as symbols in cognitive research, and there is empirical evidence that suggests that they may be processed differently. A second issue that is reviewed is how the presence of symbols/codes that are not relevant to the task being performed may affect processing. Another common relationship among codes in a display is the case where multiple codes are present in a display that signify the same response. This relationship is defined as redundancy and therefore, research that examines code redundancy is reviewed as well. Finally, the impact of the arrangement of codes in the display relative to the arrangement of codes in the response mapping is an important aspect of coding that can affect the way a task is performed. Therefore, studies that provide insight into how the response side of the task affects processing is considered in some detail.

Processing of Code Categories: Digits versus Letters.

It is interesting to note that most research that employs digits and letters does not focus on the processing of digits and letters per se. Rather, the digit and letter symbols are employed as a means of studying some other processing issue. Thus, the use of digits and/or letters is typically not considered to be important to the study of processing per se. For example, Dick (1969) evaluated the effects of identifying multi-dimensional stimuli according to one of several dimensions which included color, position in a matrix, and class (digit or letter). In his results, he makes an almost incidental note that letters were identified more accurately than digits. Thus, while Dick (1969) did not set out to study the processing of digits versus letters, his results lend credence to the suggestion

that digits and letters, though very similar categories of codes, may in fact be processed differently in the context of the same task.

Corballis & Nagourney (1978) used digits and letters as stimuli in a mental rotation task. However, subjects were required to classify a target as a letter or digit rather than identify it as is the case in the typical mental rotation task. They found that the category classification of digits or letters was not affected by degree of rotation, while the identification of a particular target code was affected by target rotation. Further, they found that the latencies to identify normal digits or letters were shorter than those for backward digits or letters. Again, these findings support the proposition that digits and letters are in fact distinct subcategories of alphanumeric stimuli. However, the data presented in the report do not offer any clues as to the relative speed for classifying digits versus letters, so there is no basis on which to speculate how digits and letters might be processed differently.

Studies utilizing digits and letters have often done so because both sets are: 1) extremely well learned in the general population, and 2) have ordinal properties among the set elements (Briggs, 1974). This later aspect of these symbol sets led Egeth, Marcus & Bevan (1972) to assess the impact of using different elements from among the digit set on reaction time performance in a binary classification task. The results of the study led these researchers to suggest that different code symbols may have implicit properties that cause them to be processed differently. They found that selecting elements among the sets such that the elements demonstrated an ordinal property, or "natural" sequence, increased response time relative to when elements were randomly selected. This suggests that subjects are aware of, and in fact process attributes of the stimulus sets which may have no explicit, operational relevance to the task being performed. If the ordinal aspects of these two categories can affect processing when the ordinal properties are not relevant to the task being performed, then it is reasonable to expect that other aspects of code categories might affect

processing as well. The findings of this research support the assertion that different symbol sets may affect performance differently, prior to their being given explicit meaning through the explicit application of a coding scheme. This further supports the assertion that differences in the letter and digit symbol sets might cause them to be processed differently.

Studies that have employed digits and letters as different categories have also generated data that may be interpreted as suggesting that digits and letters are processed differently. In three studies using digits and letters in between- and within-category search tasks, Cardosi (1986) found that there were distinct differences between the time required to search for targets when noise targets were selected from the same category as opposed to when subjects searched for targets when the noise targets were from different category. These results support the proposition that digits and letters may be processed differently. She notes that in her between category search tasks, i.e. when searching for digits or letters in a display of digits and letters, subjects were more accurate in locating targets than they were in identifying them. In within category search tasks, i.e. searching for particular digits from a display of digits or searching for letters among a display of letters, subjects were more accurate identifying targets than they were in locating them. Cardosi ascribes these performance differences to the physical differences in the digit symbols relative to the physical differences among the letter symbols rather than to the nature of the digit and letter categories per se. Regardless of the aspects of the symbol sets that generated these performance differences, their significance to this study is that they again show that digits and letters are naturally treated as distinct categories of codes, and therefore may be processed in distinct and different manners.

George E. Briggs is one of the few researchers in the literature to directly address the issue of code symbols as being processed differently. Briggs (1974) reviews the findings in published literature based on the Sternberg Task. Subjects in this task are required to memorize a number of target codes. Probe targets are then presented on a display, and subjects are asked to classify the

probes as either being a member of the memory set or not being a member. The time required to the classification is recorded over a number of trials. Typically, one factor that is manipulated in the Sternberg task is the number of items that are present in the memory set. The typical finding in this task is that the amount of time required to perform the classification increases as the number of items present in the memory set increases. In his survey of published research using the Sternberg task, Briggs notes that the binary classification of digits was best described by Sternberg's original (1966) linear regression to describe the relationship between memory set size and the predicted response time, i.e.

$$RT = a + b\,(M)$$

where RT is reaction time, M is memory set size or number of elements in the positive memory set, and a reflects a constant amount of time consisting of the time to encode the display information into sensory memory and the time required to execute a response, and b is the slope which reflects the rate of processing in Stage II or central processing (Sternberg, 1969; Smith, 1968).

Briggs notes that while the linear equation provides an excellent fit for the classification of digits, such as those used by Sternberg, an alternative form of the equation works better for most types of stimuli. Letters of the alphabet, combinations of digits and letters, random figures, geometric symbols, and pictures of faces were found to be better described by an equation that takes the $\log_2$ of the number of items in the memory set. Specifically, the equation proposed to describe the reaction time results for the classification of letters and most other categories of code symbols is:

$$RT = a + b\,(H_C)$$

where H_C is the amount of central processing uncertainty.

Briggs attributed the rather unique performance characteristic associated with digits to a several unique aspects of the digits set. The set of digit symbols was relatively small (10 elements, 0-9) and was very well learned. Further, in real-world use, the elements of the digit set are routinely

treated as *single* stimulus elements, while letters are treated as part of a larger verbal code (i.e. words). Therefore, subjects had much more experience utilizing the distinctive features of digit symbols than in utilizing the distinctive features of letters. Because the classification of targets requires attention to the individual features of the targets, the performance seen with digits was different from that seen with letters.

Briggs extended his observations to the classification of stimuli with more complex features, and/or with less discriminability. When stimulus ensembles are presented with more stimulus features (e.g. stimuli that are coded along multiple dimensions or which consist of multiple codes), or which are less discriminable (perhaps because there are a larger number of possible stimuli in the set or due to spatial proximity), more stimulus features are considered and/or more feature tests must be performed to make a correct classification than for simple stimuli. As the number of decisions required to classify targets in a task increases, the more likely is information uncertainty to be an appropriate measure when describing central processing.

The explicit suggestion by Briggs that digits and letters are processed differently, as well as the implicit findings of the other researchers reviewed above support the hypothesis that the use of digits and letters as code sets in an information processing task may lead to different effects on processing. This hypothesis will be addressed in Chapter 4.

The Presence of Irrelevant Codes.

Another issue relevant to the use of symbols in displays is that of the effects of irrelevant or noise codes on the processing of relevant codes. The effects on processing of spatially proximal noise and relevant codes were shown in studies by Wickens & Andre (1990); and Andre & Wickens (1988). The data from these studies demonstrated that the spatial proximity of information, including that represented by what the experiment operationally defines as noise, impacts on

information coding. Wickens & Andre (1990) directly tested the hypothesis that the impact of noise codes is directly related to the proximity of the noise codes to the relevant codes such that the more proximal the noise codes to the relevant codes, the greater the interference generated by the noise codes. Their results suggest that noise codes are in fact processed in working memory, and not simply filtered out at a perceptual level.

Eriksen, Eriksen & Hoffman (1986) reached similar conclusions using a different research paradigm. They employed a binary classification task to assess the ability of subjects to employ selective attention and ignore noise targets in a display which could indicate either the same response as the target symbol, or a competing response. The results of their "response competition paradigm" showed a large difference in response times to both positive and negative memory set targets when the accompanying noise letters indicated a competing response, as opposed to when they indicated the same response as the target. Eriksen, Eriksen & Hoffman interpreted these results to indicate that both the target and the noise targets are rapidly identified and input into working memory, and this is independent of the serial comparison process generally ascribed to central processing. Again, these results suggest that irrelevant (noise) targets do affect processing in some way.

The issue of noise codes and their impact on performance appears to be tied to context, and the issue of how categories of codes are processed. Not only is proximity important, but the relationship of the noise codes to the relevant target codes is a major factor in determining the effect of noise codes on performance. Studies concerned with the nature of code categories also have generated results relevant to the effects of noise codes on processing, and have related those effects to the distinctiveness of code categories. For instance, the distinctiveness of categories defined by sets of digits, letters and punctuation symbols is assessed in the work of Pashler and Baylis (1991)[a,b]. Their research is based on the assumption that digits and letters are processed

separate categories of symbols rather than a single alphanumeric category. They then examined how learning elements in one category affects performance for classifying new elements in the same versus different categories. Results from Pashler & Baylis' (1991)[a] experiments 1 and 2 demonstrated that: 1) when a classification task is defined on the basis of categorized symbols, performance is faster and generates more rapid improvements with practice than it does with randomly assigned (non-categorical) symbols, and 2) when training on a well defined category there is substantial positive transfer of training to new exemplars added in the same categories while there is minimal transfer for poorly defined categories, (see also Schneider & Fisk, 1984). These results suggest that the processing of symbols selected from digits, letters and punctuation categories are in fact processed as categories *when the task is constructed such that responses are categorically consistent*. Thus, the suggestion that digits are processed differently than letters may be dependent on the context of the task in which they are being processed.

The problems of coding in actual applications outside the laboratory are often more complex than those addressed above. Often, the display contains a number of codes and/or code dimensions that are not directly relevant to the task at hand. The question then becomes one of: What effects do the irrelevant codes have on the performance in identifying relevant codes? Again, the context of categories may have an impact on the effects of irrelevant codes on the processing of relevant codes, (Eriksen and Eriksen, 1974; La Heij and Vermeij, 1987). Proctor and Fober (1988) studied response-compatibility in order to assess the effects of extraneous stimuli presented in the display when extraneous elements were similar to the target stimuli. Their study again used digits, letters and punctuation symbols as distinct code categories, however they were interested in the effects of classifying targets when noise characters were placed immediately adjacent to the target characters. The experiment paradigm employed was a variation of Sternberg's (1966) task. The noise codes in each target could signify the same response as the target code, or could signify a different response from that indicated by the target code. This arrangement effectively created

multi-dimensional coding in the stimuli. Further, they manipulated the relevance of code categories as well as the relevance of individual codes. When the code categories were relevant to the task, all those codes that indicated one type of response were selected from the same category (digits or letters or neutral). When code categories were irrelevant, both the target and noise codes were selected from all categories (digits, letters and neutral). When category was irrelevant, Proctor & Fober found that, relative to neutral code, flanking target codes with noise codes that signified the same response led to a higher rate of target classification for the relevant target codes than flanking target codes with noise codes that signified a different response from that of the relevant target code. When category was relevant, similar performance was found, however presenting new exemplars from the same category as the target code also enhanced performance, while new exemplars from the noise category slowed the rate of target code identification.

Several important points can be gleaned from Proctor & Fober (1988) with regard to the issue of how various codes and code categories in a display affect task performance. First, their results are in accordance with those of Pashler & Baylis (1991)[a] in showing that digits and letters are perceived as separate categories when the task allows category to be a relevant dimension. Further, the results of Proctor & Fober show that the presence of irrelevant information (codes) in a display will affect performance regardless of category. Under certain conditions, when the noise codes are not relevant to the task at hand, but are relevant to other aspects of the task, the effects of noise stimuli may enhance performance while in other conditions the effects may be detrimental to performance.

Stone (1979), in his review of studies that assess the effects of extraneous (i.e. noise) stimuli on latency to categorize targets, notes that the impact of code noise in different kinds of tasks is inconclusive. For instance, some investigations of latencies in categorizing tasks report little or no slowing due to the presence of irrelevant information (e.g. Morrin, Forrin, & Archer, 1961; Fitts &

Biederman, 1965; and Imai and Garner, 1965). These studies showed that irrelevant code attributes had no significant effect on speed of card sorting. However, in a complex categorization task involving four relevant dimensions, Hodge (1959) found significant increases in response latency as the number of irrelevant dimensions was increased from one to three.

In summary, the literature regarding irrelevant stimulus codes is not conclusive as to whether irrelevant codes affect performance. It has been suggested that one possible factor which relates to the effects of noise codes is whether the stimulus dimensions that make up the noise codes are ever relevant to the task being performed. When the noise code dimensions are relevant, e.g. when the noise and target codes are both from the same category, it is more likely that the noise will have a detrimental effect on performance (Egeth, 1966; Proctor & Fober, 1988; Pashler & Baylis, 1991[a,b]). Chapter 5 will take up this aspect of processing when relevant codes are identified from targets including codes from an irrelevant category.

Code Redundancy.

Redundant codes are two or more codes which can mean the same thing. In an information processing task, two codes are redundant when they both signal the same response. The processing of redundant target codes is often compared to that of extraneous (noise) codes because, conceptually, both redundant and extraneous codes provide no additional information which contribute to the performance of the task. By definition, fully redundant stimuli provide no additional information because the occurrence of the redundant stimuli is perfectly correlated with each other (Estes, 1972; Stone, 1971). The general finding with redundant targets is that the identification (processing) of redundant targets is faster than that seen in the presence of noise targets with comparable displays (Biedermen and Checkosky, 1970; Eriksen and Lappin, 1965; Holmgreen, Juola and Atkinson, 1974; Grice, Canham & Boroughs, 1984). However, the findings with redundant targets have not been consistent.

In his 1969 study, Dick used multi-dimensional stimuli which could be described in terms of their position (row or column), color (red or black) and class (digits or letters) in a memory recall experiment based on the partial report procedure (see Sperling, 1960). He found that: 1) The accuracy of recall decreased with spatial and code information, but not for class; 2) Recall accuracy was slightly biased in favor of top row, red items, and letters. These results were interpreted as showing that stimulus dimensions subject to structural properties (e.g. color, position, shape, etc.) are subject to memory decay, while dimensions subject to control processes (i.e. strategies such as rehearsal, set or category,) are less subject to decay. Digits and letters, because they may be readily rehearsed and/or classified, are responded to more accurately.[1] Thus, the impact of redundancy on processing may depend on the particular nature of the codes being used.

Flowers & Garner (1971) reach essentially the same conclusion as Dick regarding redundancy. They suggest that any task where performance is state limited, e.g. where the primary factor limiting performance of a task is visibility, will see an improvement in performance with code dimension redundancy. No benefit for redundancy will be seen when a task is process limited. Flowers & Garner performed an experiment where stimuli had either a low visibility or high degree of stimulus feature similarity. Their results confirmed their expectation suggesting that redundancy enhancement is essentially a perceptual phenomenon.

Grice and Gwyne (1987) used a letter classification task to assess the effects of code redundancy, and compared the rate of performance with redundant, noise and non-noise codes in a display. Subjects identified each type of letter that appeared in a four element display. Their experiment compared the rate of target identification when cells not containing targets contained either: 1) no targets, 2) noise letters (letters that were not to be classified), or 3) redundant letters

[1] For a theoretical discussion of structural properties versus control processes see Atkinson & Shiffrin (1968).

(non-target letters that were the same category as those that were to be identified). They also examined the effects of experience with redundancy, noise and non-noise targets through the use of both between- and within-subjects designs. Grice & Gwyne found that benefits for redundant targets were greater when subjects had never experienced noise targets. When particular target codes were noise on some trials and redundant on others, the difference in performance between them was small. Grice & Gwyne conclude that the benefits often seen with code redundancy are largely due to the elimination of the deficits associated with target noise rather than increases in performance due to the presence of redundant targets per se.

Stone (1971) in his study comparing color, form, color-irrelevant form, form-irrelevant color, redundant form-color, found that: 1) Targets that were color coded alone were identified faster than when they were form (or shape) coded alone; 2) The presence of irrelevant information increased response latency, and increases were greater when the irrelevant attribute was one which subjects responded to more rapidly (i.e. color); and 3) Redundant information did not increase the rate of responding. This study demonstrated unique findings with regard to the effects of redundancy on processing because when the task involved processing intensive tasks, redundancy slowed responding for most subjects.

As with noise codes, impact of presenting redundant codes on processing in an identification task is unclear. It appears that redundant codes may enhance, be detrimental to, or not affect performance at all, depending on a variety of issues including relevance of the redundant codes, and experience with the particular redundant codes, and the particular dimensions (or categories) of the redundant codes. The use of redundant digit and letter codes will be addressed in this report in Chapter 7, where performance with the fully redundant digit and letter codes will be compared to the identification of letters in the presence of noise digits, and where both digits and letters are identified with no noise targets.

The effects of Response Mapping on Processing.

It is not clear how factors relating to the response side of the task affect processing. However, a number of researchers have generated findings that support the proposition that relatively mundane aspects of the response side of the task may have an impact on the nature of processing. One aspect of the studies by both Proctor & Fober (1988) and Pashler & Baylis (1991)[a,b] which relates to this issue is their finding that the assignment of codes in the response mapping impacted the rate of target classification. Specifically, Proctor & Fober found that when noise codes were mapped to the same or different response buttons as relevant codes, the rate of identification was significantly slower. This led Proctor & Fober to suggest that there was response competition between the relevant and irrelevant codes and this caused adjacent noise codes to enhance or decrement performance. Therefore, the response mapping did contribute to the processing that went on in stage 2, or central processing in the Sternberg processing model (Sternberg, 1966; Smith, 1968).

Studies reported by Pashler & Baylis (1991) [a,b] also have implications for how the response side of a classification task affect processing. One of the Pashler & Baylis (1991)[a] experiments replaced one element of the classification set in a categorical classification task after 750 trials of practice, e.g an old exemplar from a category was replaced with a new exemplar from the same category. They found that performance in terms of the rate of responding was slowed down to a level comparable to that seen after 100 trials when all the original exemplars were first being learned. Another experiment used what they called a "shuffled mapping procedure" where the response keys for the different categories were rearranged after 750 trials of practice. In addition, they added new exemplars to the categories for half their subjects in this experiment. They found that: 1) the shuffling of the response mapping created a massive disruption of performance, and 2) the new exemplars improved after the disruption much more rapidly after the shuffling than did the old exemplars. In yet another part of their study, Pashler & Baylis used a procedure where after 750

trials the response mapping was held constant, but subjects were required to respond using the opposite hand from the one that they were trained on. The results of this study showed minimal deficits in performance, suggesting that the competition was occurring in the mapping of codes, rather than during the execution of the responses per se.

Taken together, the results of Pashler & Baylis (1991)[a] show that: 1) response mapping can have major impacts on performance in terms of both how the task is learned and how fast the task is performed; 2) response mapping effects may interact with cognitive aspects of the stimuli being processed in performing the tasks, and 3) the effects of response mapping are in fact on both the perceptual (categorical) stage(s) of processing and at the level of response selection. Pashler & Baylis (1991)[b] continued this line of research by examining the effects of repetition of exactly the same target in consecutive trials. Their results in these studies cause them to suggest that the effects of both practice and repetition are in large part located in the response selection stage of the Sternberg model, and further that the speeding up of responding is both narrower and more specific with response repetition than it is for the general practice effects. Thus, the impacts of response panel manipulation on processing may be qualitatively different from those that are attributed to manipulations of the codes presented in the display.

The effects of movement in the execution and selection of responses are also studied using the movement precuing method. In this methodology, cues are provided to the subject that indicate the direction and/or extent of the movement required prior to the start of an experimental trial. Larish (1986), in his assessment of the validity of the movement precuing method for assessing the influence of stimulus-response translations on movement programming, presents data which suggests that some part of response programming begins very early in processing, (see also Rosenbaum, 1980). The movement precue method involves presenting cues as to the direction and/or magnitude of a correct movement. Larish presented a task in which the cues were incorporated into a modified

additive factors method classification experiment (after Sternberg, 1966). The cues on the display were manipulated so as to be spatially compatible or incompatible with the response panel. For some conditions, the cues were highly compatible, for some they required some translation (translating from a vertical to horizontal orientation), while for others they were incompatible (indicating the wrong direction and/or magnitude of movement). His results found that stimulus-response compatibility interacted with memory set size, showing that some aspect of the arrangement of codes in the response take place in central processing (as defined by E. E. Smith, 1968; Sternberg, 1969). This finding is important because it leads to the supposition that factors relating to the stimulus-response translation, or output side of the task, can interact with and affect the processing of other display and task factors, e.g. the input side of the task, due to their being processed at the same time.

Hendrikx (1986) notes that the size of the slope of increase in reaction time in a choice reaction time (CRT) task with changes in the number of alternative choices is also a function of stimulus-response (S-R) compatibility, (e.g. Welford, 1968; Teichner & Krebs, 197‹ , and Sanders, 1980). In his study, subjects were given a precue indicating which subset the target would be chosen from, and the effect of a correct or incorrect precue was assessed in conjunction with manipulations of S-R compatibility and number of items in the memory set. The goal in these manipulations was to see if the precuing effects were indeed modulated by S-R compatibility, and therefore whether precuing affected central decision processing or simply motor programming. The results of the study indicated that precuing reduces the processing load and the structure of response programming because aspects of the motor program may be completed in advance with the occurrence of an appropriate precue. Hendrikx concludes that S-R compatibility exclusively affects response decision processes in that less compatible S-R relations increase the complexity of the translation from signal to response code.

In overview, it appears that the response mapping can have an effect on not only the time required to perform a task, but the way that other factors in the task affect performance. The effects of the response mapping will be a central theme in the research described in the remainder of this paper. The studies described in Chapters 4 through 6 will all assess the effects of response mapping to determine both the impact of response mapping on input and output processing, and the interaction of response mapping and task demands defined by the codes used in an identification task.

Summary.

This review of the literature has illustrated that there are a variety of issues related to the relationship of codes and particular task demands that deserve further examination. First, it is not clear how the use of similar symbols from different code categories may affect information processing. Specifically, the literature suggests that digits and letters may be processed differently even when there is no explicit significance given to the digit and letter categories. Further, the effects of processing of symbols from one category in the presence of symbols from another category is unclear. Specifically, the effects of extraneous symbols on the processing of relevant symbols merits further clarification, as does the processing of fully redundant symbols. Further, the effects of processing relevant codes from multiple categories merits examination relative to the processing of codes from single code categories. Finally, the literature suggests that the presence and arrangement of different categories of codes on the response side of the task may have a significant impact on information processing. The specific nature of those effects, however, are unclear. The research described in the remainder of this report will describe a series of studies that address these issues in the context of an identification task and an alternative response time partitioning methodology. The rationale for this methodology, its historical antecedents, and its applications to date are reviewed in the following chapter.

CHAPTER 2 - Response Time Partitioning Methodology & Models.

Collectively, studies which use response time as the basis for studying cognition are known as choice reaction time (CRT) experiments (Luce, 1986; Welford, 1980[a,b]; Laming, 1968). The research reported in the remainder of this paper uses such a CRT procedure. However, the methodology employed is relatively unknown in the experimental psychology literature, and has come to be known as the Within-Task Subtractive (WiTS) methodology. As with other response time partitioning methods, the WiTS methodology has become important to the study of information processing because the processing takes time. Therefore, while it may not be possible to study the actual mechanisms in the brain that control behavior, the pattern of changes seen in the time required to process information can be studied. Hypotheses regarding the nature of the mechanisms behind processing may thus be tested in terms of how those mechanisms should affect response time. If the tasks being measured are discrete, i.e. have a definite beginning and a definite end, and if adequate controls and assumptions are used, it is possible to make inferences about the nature of the mechanisms that might have contributed to a behavior by assessing the time required to complete the task. This chapter reviews the major paradigms used to look inside the "black box" of human behavior, as well as the major findings and assumptions on which these paradigms are based[2]. By the conclusion of this chapter, the reader should have a theoretical understanding of the WiTS methodology, and its advantages relative to the other response time partitioning methodologies that are currently available. The utility of the WiTS methodology will be further illustrated by the studies described in the remainder of this paper.

---

[2]For a comprehensive review of the use of response time as a dependent measure, the reader is referred to Luce, (1986) and Welford, (1980). An excellent summary of the use of Reaction Time in information processing is Pachella's (1974) review.

Laming defines a CRT experiment as:

> "... a series of trials, on each of which the subject is presented with a signal chosen from a finite set of signals, and makes a response as soon as possible after the signal appears. There is a definite response for each alternative signal (or class of signals) and the subject must make that response which corresponds to the signal presented. Although the subject knows roughly when the signal will come, he does not know which signal it will be and is therefore uncertain about which response he will have to make. A typical experiment involves the visual display of a target or targets, which have some meaning to the subject depending upon the instructions he has been given. The subject, as quickly (and accurately) as possible, responds to the display in the correct manner. The time required to do this includes not only the time to notice one of a certain set of changes in the environment, but also the time to decide which key should be pressed. A 'Choice-Reaction Time' therefore includes decision time." (Laming, 1968, p. 1)

Teichner (1977) characterizes CRT experiments by discussing the critical elements of tasks involving free recall. In these tasks, subjects are typically presented with an array of symbols in a visual display. After the display is removed, the subject's task is to identify either all or some subset of the targets through a series of either vocal or manual responses. Teichner notes that, because the display is no longer present, any responses that are made must be made from memory. Sperling's (1960, 1963) early work using free recall and a partial report procedure further demonstrated the existence of several types of memory, specifically a sensory store, and in so doing made it clear that the different processes in memory could be isolated on the basis of time. Sperling generated evidence that the representation in sensory memory is very volatile, and was readily destroyed by the disruption of the sensory presentation, while that stored in working memory was much more enduring. Thus, it is generally agreed that there is at least one additional kind of memory which is suitable for the longer term storage of the information in the display. This memory is referred to as short-term memory or working memory (Broadbent, 1971).

In order to study the manipulation of information in memory, i.e. processing, it is desirable to try and identify and study changes in each of the processes thought to occur in the course of performing a task. Therefore, various researchers have developed theoretical models of what

processes they believe take place in the course of performing a discrete task, and have then developed procedures that partition the total response time into portions that reflect the different theoretical processes. These procedures are referred to as response time partitioning methodologies.

The ideal response time partitioning methodology should generate measures that are as independent as possible from any particular model of information processing. This ideal methodology will generate empirical results that do not rely on underlying assumptions, and therefore any results obtained using the methodology will have generality beyond the theoretical framework in which the methodology was developed, (Teichner, 1977). There have been three major paradigms applied to the problem of studying human behavior through the partitioning of response time. They meet Teichner's criteria for the ideal measure of processing to various degrees, as evidenced by the assumptions they employ in partitioning response time, and the criticisms have arisen from those assumptions. Two of these response time partitioning procedures are fairly well known and documented in the literature. These have come to be known as the subtractive method, developed by Donders (1969), and the additive factor method, developed by Sternberg (1969). The WiTS methodology, which is that used in the research described in the remainder of this report, has received relatively little attention, due, in part, to Teichner's death shortly after it was developed. Therefore, a considerable portion of this chapter will be dedicated to reviewing its assumptions and applications to date.

Donders' Subtractive Method.

The earliest successful attempts to use response time as a basis for studying human cognition through the use of response latency are widely attributed to F. C. Donders (1868).

Donders began his research with a model of processes (stages) that occurred between the onset of a stimulus and the execution of a response. This model is shown as Figure 2-1. In the model, the time between the occurrence of the Stimulus (S) and Response (R) consists of a series of discrete mental acts, such as the time to sense (detect) that a signal had occurred, the time to identify what that signal was, and the time to determine what response was to be made to the signal presented. Donders then proposed a method for determining the duration of the various stages. He suggested that the time to carry out a specific mental subprocess which occurred within each stage could be inferred by running pairs of trials that are identical in all respects except that in one the subject must use the particular process while in the other it is not used. By subtracting the time required for performing the task without the process (or stage) of interest from the time required to perform the task with the process of interest, one could obtain an estimate of the time required for an individual stage.

Donders' seminal paper reported data for several different classes of stimuli involving both simple and choice reaction times. In his first experiment, Donders used speech sounds as stimuli, and measured the time required for subjects to produce the same speech sounds after hearing a spoken stimulus (Woodworth, 1938). In later studies lights were used as stimuli and button presses were used as responses (Luce, 1986; Welford, 1980[a]). In what was effectively a simple reaction time task, Donders would pronounce the syllable "Ki" and the subject would respond by pronouncing the same syllable as quickly as possible. Donders termed this the *a*-reaction, and consisted only of the time to control and execute a motor response. On average, Donders found the *a*-reaction to require 197 msec. In what was termed the *b*-reaction, Donders would pronounce any one of the five syllables "Ka, Ke, Ki, Ko or Ku". The subject responded by pronouncing the same syllable. This reaction, which entailed the recognition that a signal occurred, the time to identify the signal, and then the time to choose the correct response, required 285 msec. on average. Finally, the *c*-reaction involved the time required between the experimenter's pronouncing any of the five syllables and the

subjects responding only when he heard the "Ki" syllable. The *c*-reaction was argued to consist of the time to recognize that a signal had occurred and to identify which signal had occurred, it required 243 msec. on average.

Donders argued that the difference between the time required for the reactions corresponded to the difference in the time requirements for theoretical stages present in the different reactions. Subtracting the time required for the *a*-reaction from the time required for the *c*-reaction corresponded to the time required for a single sensory discrimination because the *c*-reaction theoretically contained a single discrimination, while the *a*-reaction contained none, (c-a = 46 msec.). In all other respects, both procedures were assumed to have the same basic requirements. Subtracting the time required for the *c*-reaction from the time required for the *b*-reaction corresponded to the time required to chose among the available responses since the *b*-reaction had multiple choices while the *c*-reaction had only one, (b-c = 42 msec.).

While the subtractive method was used extensively through the late 1800's, it has been used relatively little since the early 1900's because of a number of criticisms. Luce (1986) collects these into four major categories. The first, which Donders himself discussed, is that subjects may not always wait until a signal is identified before initiating a response. Trials that are anticipated are problematic because they cause the time required for identifying a stimulus to be underestimated, and this in turn leads to over estimation of the time required to chose among the responses when the subtraction of time estimates for each of the stages is performed. This criticism may be valid for other approaches to partitioning CRT as well, and has not proven fatal to any of them because there are methodological and statistical procedures available to help deal with the problem of subject response anticipation (Luce, 1986; Laming, 1968; Woodworth, 1938).

Figure 2-1. Donders' Choice Reaction Time Model.

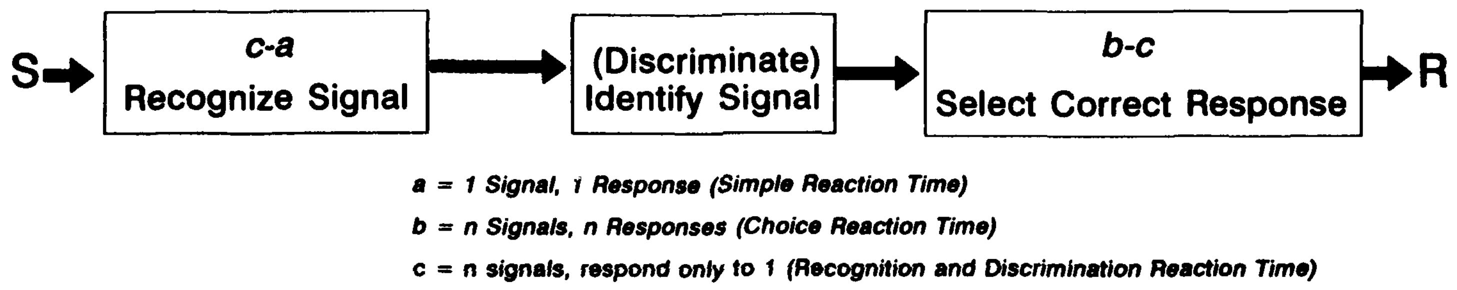
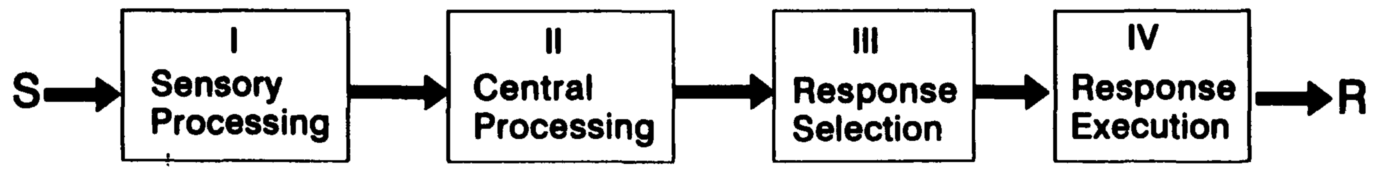


Figure 2-2. E. E. Smith / Sternberg Choice Reaction Time Model.



The second major category of criticisms centers around the assumption of choice as being a purely serial process. While Donders did not explicitly make this assumption, his work does implicitly rely on it because, in order for the times for each of the separate processes to add, they must each occur in a distinct, sequential and non-overlapping sequence (Teichner & Krebs, 1974). Again, as will be made clearer in the discussion of the additive factor method below, there are empirical means by which to assess the validity of this assumption, so it need not be fatal for the application of Donders' subtractive approach.

The third class of criticisms relates more to the specific procedures used by Donders in developing his approach to partitioning response time. The criticism, which was first pointed out by Cattell (1886) is that Donders' *c*-reaction involves more than pure identification since the subject performing the task must in fact make a response decision in performing the task. In the *c*-reaction, the subject was to respond when one stimulus appeared, and not if some other stimulus appeared. However, in choosing whether or not to respond, the subject has in fact made a choice, and therefore the *c*-procedure does entail a choice, contrary to Donders' assertion otherwise. Welford (1980) suggests that despite this problem, the empirical evidence does suggest that Donders' approach was essentially correct, and the main consequence is that, Donders' procedure will over estimate the time required for recognizing that a stimulus has occurred. Thus, the *c*-procedure does involve less choice than the *b*-procedure, and Donders was simply wrong in assuming that all choice of response was eliminated in the *c*-reaction. Therefore, this criticism, while problematic for the subtractive method, does not eliminate its utility in understanding performance and comparing the effects of various manipulations on the times required for the different procedures.

The fourth class of criticisms has proven to be the most problematic. In fact, this criticism has proven a major factor in putting the subtractive method out of favor with cognitive research since the early 1900's. This criticism involves the assumption of "pure insertion". Pure insertion

refers to the assumption that it is possible to add or remove a stage of processing without in any way affecting the remaining stages (Luce, 1980; Sternberg, 1969). If this assumption is not valid, then the differences between reaction times in the different procedures can not be identified as representing the duration of the inserted stage, but may in fact be due to changes in the remaining processing stages as well as, or instead of the removal of the stage. Donders did not appear to be aware of this criticism, and there is little one can do to empirically test this assumption (Luce, 1980). However, Briggs has generated data that lend support to the validity of this assumption in that he generated independent estimates of the duration for the *a*, *b*, and *c* reactions using additive-factor methodology. This would suggest that the assumption of pure insertion may be appropriate, at least under some conditions.

A fifth category of criticisms has been presented by Teichner & Krebs (1974). They note that in effect, the *a*-procedure corresponds to simple reaction time. Simple reaction time in the Donders model represents the sum of various neural transmission lags, and is implicitly assumed to be a constant for any level of stimulus energy. There is empirical data, however to show that this is not the case, and in fact is a pseudo-random variable, and an alternative conceptualization, such as that of the random-walk model might be more appropriate to describe the performance seen in simple reaction time (Teichner & Krebs, 1974; Laming, 1968; Fitts, 1966). The consequence of the *a* component being a random variable is that the estimate for the choice (*b*) component of the model also becomes a random variable, and the estimate is likely to differ depending on the particular stimuli used in the subtractive estimation procedure. Such a result suggests the findings from a study using the subtractive method would not be generalizable, and therefore have limited utility in predicting performance in studies where different stimuli are used.

A sixth category of general criticism is suggested by Pachella (1974), and is related to the assumption of pure insertion. This criticism centers around the starting point in Donders' approach

to response time partitioning which is fairly sophisticated. That is: "In order to construct a comparison task, one must already know the sequence of events that transpire between stimulus and response." (p. 47). Knowledge of the order of events is rarely available, and represents a very sophisticated assumption based on logical or intuitive, as opposed to empirical justification. Therefore, use of the subtractive methodology requires that the researcher make a rather bold and unsubstantiated assumption about the nature of stages which are present in order to employ the subtractive procedure.

The numerous criticisms of Donders' subtractive approach to partitioning response time have led to its relatively infrequent use in modern cognitive psychology. However, response, (reaction), time continues to be an important part of cognitive research. One reason for the continued popularity of response time as a measure of human information processing is the availability of alternative response time partitioning methodologies, the best known of which is that developed by Sternberg, (1966), which is commonly referred to as the additive factor method.

Sternberg's Additive-Factor Method.

While Donders' focus in cognitive research was to identify the duration of stages in processing that had been selected on an a priori basis, Sternberg's (1969a, 1966) approach to the partitioning of response time was developed with a concern for: 1) determining what and to what degree different experimental factors affected the same stages of processing; and 2) identifying what stages might in fact constitute processing in a CRT task. Sternberg revised Donders' method of subtraction to create what has come to be known of as the additive-factor method. The essential difference between Donders' method and Sternberg's lay in the Donders' reliance on the assumption of pure insertion, i.e. that stages in processing could be added and removed from a chain of

processing stages without affecting the remaining stages. Sternberg suggested an alternative assumption, namely that variables could be manipulated that only *affected* some stages and not others, rather than eliminating them. The effect seen from manipulating these variable would show up as patterns in the way different variables did or did not interact with each other. This assumption, though weaker and less stringent than Donders' assumption of pure insertion, would prove very useful because it allows the existence of stages to be empirically tested in a manner that was not possible with the subtractive method.

Sternberg (1966) demonstrated this methodology with a task where subjects memorized a short list of letters at the start of each experiment trial. This list is referred to as the (positive) memory set. The subject was then presented a probe stimulus, (visually in Sternberg's original task), and asked to classify the target as being present or absent in the memory set by pressing one of two response buttons as quickly as possible after the presentation of the probe stimulus. The time required from the onset of the probe until the execution of the response defines the reaction time. This binary classification task is the heart of the Sternberg procedure, and is the core task for all conditions within the additive factor methodology.

The additive-factor methodology manipulates at least two aspects, or factors, of the binary classification task performed by the subject. The researcher can then assess how the reaction times obtained from different levels of those factors interact. The additive-*factor* method receives its name because it involves the performing of multiple comparisons of the same task with multiple levels of each of the factors of interest being compared to each other. The presence of stages is inferred empirically by assessing the "... *pattern* of data which is the result of a *set* of operations", (Pachella, 1974, p. 51). For example, Sternberg's (1966, 1969a) original procedure manipulated the number of items (letters) present in the positive memory set and the legibility of the probe stimuli presented on the display. Sternberg made the assertion that the number of items that had to be compared in

memory would affect a central processing stage in memory (Figure 2-2). This assertion was based on the observation that the number of alternatives generated a function corresponding to the information content defined by the size of the memory set (Hyman, 1953; Hicks, 1952; Merkel, 1885). If the legibility of the targets affected the same (central) processing stage, there would be a statistically significant interaction between the two factors: number of items in the memory set, and, levels of legibility of the probe stimuli. Sternberg's results showed that while there was an effect of reaction time due to stimulus legibility, there was no statistical interaction between the target legibility and the number of items in the memory set. This led him to the conclusion that the legibility of the probe stimuli affected only sensory processing, i.e. the way information was collected from the display prior to being sorted as information. These, and later results generated support for a four-stage processing model, which is shown as Figure 2-2.

Sternberg's additive-factor method has proven popular in the conduct of information processing research for a variety of purposes. The focus of this research has been of two general types. Research such as that of Morrison, (1987), has applied the additive-factor method to such problems as the effects of different information coding dimensions on information processing, which are centered around a concern with what factors affect the different stages. Work such as that by Briggs and his students has focused on extending the logic of the additive factor method to identify different stages and assess their duration within the general model proposed by Smith (1968) and Sternberg (1969a). Specifically, Briggs and his students have used the additive-factor methodology to: 1) assess the impact of differential information properties among the positive and negative memory sets to assess information processing of the sets; and 2) to identify what subprocesses could be identified within the different processing stages[3], (Mudd, 1983).

---

[3]See the following for extensions of the additive factor methodology in identifying stages of processing: Briggs & Blaha, 1969; Swanson & Briggs, 1969; Briggs & Swanson, 1970; Briggs, Peters & Fisher, 1972; and Briggs, Thomason & Hagman. For a comprehensive survey and analysis of Briggs' work see also Mudd, 1983.

Despite its popularity, the additive-factor method has received criticism, mostly centering around the assumptions necessary to utilize it rather than around any fundamental logical problems per se. This is why the method has, and still does, remain in use for the study of human information processing. The first criticism has centered around the assumption that the manipulations of factor levels may cause a fundamental change in the nature of processing. For instance, it is conceivable, though arguably unlikely, that changing the factors manipulated in the additive-factor method may also change the order in which stages of processing occur. Such an argument seems unlikely, and there has been no definitive empirical support showing that this happens. None the less, it remains a popular argument. However, this argument has taken another form which has proven somewhat more problematic. This argument is that processing might be more appropriately characterized as parallel rather than as a series of non-overlapping sequential, and therefore stochastically independent stages[4]. The requirement of the additive-factor method for a series of stochastically independent stages has not been definitively proven as appropriate or inappropriate, and therefore remains an assumption to be accepted or rejected at the discretion of the individual researcher.

A second criticism, and one for which Sternberg himself urged caution, relates to the assumption of additivity in multi-factor experiments. In essence, the failure to find a significant interaction between the levels of two (or more) factors in an additive factor experiment is taken for evidence that the two factors are simply additive in their effect on processing, and their effects are represented by the intercept term in the additive factor model, (Luce, 1987). However, as pointed out by Pachella, (1974), this amounts to accepting the null hypothesis concerning the interaction of the two (or more) factors. Great caution needs to be exercised before this is done. The problem is

[4] Alternative models have been proposed to account for the results of binary classification experiments. Ellis & Chase, (1971) proposed a parallel processing model. What has come to be known as a cascade model where the stages are serial, but overlap in time, was established by McClelland (1979) and confirmed by Ashby, (1982). Morrison, (1987) resorted to a cascade model to account for non-linear effects as a function of the interaction of memory set size, hue and stimulus contrast in a binary classification task. See these authors for a more extensive discussion of alternative processing models to that advocated in the additive factor method.

generally surmountable, however, through the use of appropriate controls and precision in the conduct of the experiments (see for example the work of Briggs and his students).

Another major criticism of the additive factor method, and one which is relevant to the subtractive method as well, is the issue of speed-accuracy tradeoffs. Sternberg, like Donders, simply assumed that subjects could, and would, perform their tasks as quickly and accurately as possible, and therefore there would be no need to assess if individual subjects were changing their criteria of performance with regard to speed and accuracy (Luce, 1986; Pachella, 1974). This becomes an issue because it has been shown that subjects can become more accurate in making decisions by slowing their rate of responding or become less accurate in responding by increasing the rate at which they respond. Thus, in effect it is possible for speed and accuracy to be perfectly confounded for an individual subject. This criticism is readily dealt with, however, by measuring both speed and accuracy in a procedure and comparing the relative changes in each measure as a function of the experiment manipulations, (Pachella & Pew, 1968).

The final problem with the additive-factor method that will be discussed has to do with the degree to which it can be applied in domains other than the binary classification task. The problem arises in the conception of what constitutes an "information processing" stage. The definition is fairly clear as long as one sticks to the basic procedure and manipulation employed by Sternberg, i.e. the number of elements in a memory set. However, as one moves from the domain of the binary classification task to other domains, the relevance and appropriateness of the definition within the additive-factor methodology is often less certain and can become controversial. In effect, the question of the relationship of the research outside the binary classification task to that which utilizes it becomes an empirical question, and not one which can be readily resolved on a theoretical basis (Luce, 1986; Pachella, 1974). However, this concern has limited the utility of the additive factor methodology, and applicability of its findings to real-world human performance problems.

Teichner's Within-Task Subtractive Method.

Teichner (1977, 1979) developed what has been referred to as the Within-Task Subtractive (WiTS) method for partitioning response time to assess in more detail the experimental paradigm for free recall, such as that used by Sperling (1960, 1963) wherein the effects of sensory memory were isolated from those of working memory. Teichner reasoned that it might be possible to isolate other memory phenomena, such as that of response blocking[5]. The question which came to be of interest for Teichner was if such phenomena could be isolated in terms of being either an input or output phenomena. The search for an alternative procedure which would be more robust than those of the subtractive and additive factor methods and would avoid their criticisms contributed to his developing the WiTS methodology, (Teichner, 1979, 1977).

Considerable time will now be spent in describing the development of this methodology and its basic assumptions. This is done for three reasons. First, the WiTS methodology should have significant appeal to both the applied and theoretical researcher because it has fewer and less stringent assumptions than the alternative response time partitioning procedures available to the human performance researcher. The fact that there are fewer assumptions means that the WiTS methodology should be applicable to a wide variety of research problems and domains, many of which were not readily addressable with the earlier partitioning methods. Second, the WiTS methodology has remained relatively obscure, and as such the reader is less likely to be familiar with it than the more prominent subtractive and additive factors methodologies. Third, this methodology will be the focus of the research described in the remainder of this report. The remainder of this chapter, therefore will review Teichner's development of this methodology, and then will survey its

[5]"Response Blocking" as defined by Teichner (1978, 1964) refers to the phenomena in immediate recall paradigms where the subject is unable to "get the response out", though it is clear that at least some representation of the response is available in memory. It is analogous to verbal "tip-of-the tongue" experiences.

application to date. Finally, the issues to be addressed in the studies described in Chapters 3 through 8 will be introduced in the context of the WiTS methodology and model.

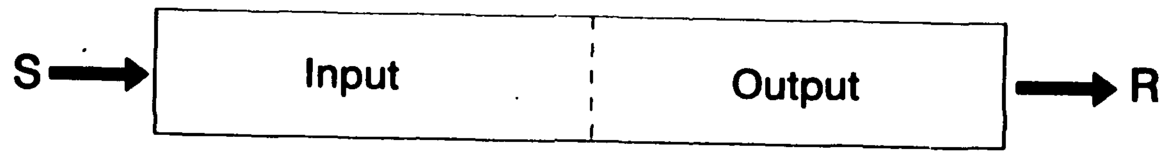
Teichner developed the WiTS methodology by beginning with the assertion that following the onset of a display, the stimulus items presented in the display are somehow acquired, encoded and stored in a final, non-sensory memory. All these activities are defined as belonging to "input". Further, all activities that follow the storage of information in memory, including response selection and execution, are defined as belonging to "output". This model is shown as Figure 2-3 The sole goal of the WiTS methodology is to separate temporal requirements of input from those of output, (Teichner, 1977). Teichner notes that the only requirements of a processing model that are critical to this methodology are:

1) The requirement for a non-sensory (e.g. working) memory, and
2) The requirement that input stops and output begins when all of the items to be store in memory, have been stored.

Further, precisely what happens within the input and output stages exceeds the requirements and concerns of the fundamental model. However, as shall be pointed out in Chapters 4-8 of this report, it may be possible to make inferences about those processes in input and output and how stimuli are processed within them.

The task Teichner developed to exemplify this methodology is characterized by the presentation to the subject of a multi-cell display matrix and a response panel with multiple responses. The stimuli to be processed are presented in some or all of the cells within the display matrix. After a set period of time, or beginning with the subject's first response, the display matrix is removed from view and the subject responds as quickly and accurately as possible by pressing buttons on the response panel in series with a single finger. Succeeding trials may be initiated by the subject's pressing and holding a "Home" button on the response panel, the release of which

Figure 2-3. Teichner's WiTS Processing Model.



blanks the display and serves to ensure that each response sequence begins from the same point on the response panel. The response time on each trial is measured from the onset of the display. Response times are measured for each of the responses made on the response panel. Output time is defined by determining the mean time required for each of the second through final responses on any given trial. This time is denoted as the time per response (t/r) in Teichner's articles. The first response on any given trial included the time to input the information of the display to memory and make the first response. Therefore, input time is calculated as the response time for the first response less the calculated output time for one response (t/r).[6]

In order to further analyze what is provided by input time and t/r as such, Teichner suggests that two additional assumptions are required. Note, however, that these assumptions are not required for the methodology per se, but rather, allow input time to be converted to a rate measure comparable to t/r. These assumptions are:

3. At least some portion of the input involves handling the stimuli in a serial manner. This assumption is explicitly required if input time is to be converted to a rate measure.

4. Everything that is in memory receives *some* degree of output processing. Given that there is no direct way to assess the contents of memory, and/or precisely what the subject looked at, this assumption makes it possible to assign the loss of information to input or output[7].

---

[6]The observation that input time is calculated by subtracting the mean time per response for the second through final responses on any given trial from the time to make the first response on the same trial is what led Corso & Kelley, (1983) to coin the name "Within-Task Subtractive (WiTS)" to describe Teichner's partitioning methodology.

[7]It will be shown in the studies described in the later chapters of this report that it may be possible to work backward from the empirical data and speculate, to a limited degree, on the contents of memory, i.e. to reverse engineer the performance seen. This is possible by adopting a technique similar to that used in the additive factor methodology wherein the interaction of certain experimental manipulated factors are assessed in a factorial design to assess how they affect processing in input and output. This approach may make this assumption unnecessary. Further, the use of eye movement measurement techniques and the assumption that visual dwells correspond to the input of information may allow this serial input of information to be assessed empirically. See

Teichner spends a considerable amount of time assessing the means by which to assess the rate of stimulus input, denoted as the time per stimulus (t/s). The issue which arises in assessing t/s is whether t/s should be calculated on the basis of the number of explicit stimuli in the display (N_S) or the number of responses required to complete a trial (N_R). Teichner was concerned with the calculation of t/s in the event of the occurrence of trials where subjects made incorrect responses. In order to deal with the problem of calculating t/s when the number of responses did not equal the number of responses expected, e.g. the number of stimuli (N_S), He discusses this issue through the use of four cases, which shall now be described in turn.

Case 1. If an independent variable is manipulated, and an effect is found in t/r but not in input, then the loss of information is in the output, and assumption 4 is not relevant to the calculation of t/s. On the basis of assumption 3, t/s should be defined by dividing input time by the number of stimuli (N_S).

Case 2. If an independent variable is manipulated, and an effect is seen neither in input time or t/r, then assumption 4 is relevant, and t/s is defined on the basis of dividing input time by the number of responses (N_R).

Case 3. If the variable has affected input time, but has not affected t/r, then on the basis of assumption 4, t/s is defined on the basis of N_R.

Chapter 5 for a more in depth discussion of this topic.

Case 4. If the independent variable has affected both input time and t/r, the loss of information in processing cannot be known a priori. Therefore, Teichner (1979, 1977) argues that the t/s cannot be calculated in a meaningful way.[8]

Applications of the Within-Task Subtractive Method.

The remainder of Teichner's (1977) technical report is dedicated to illustrating the utility if the idea of input and output time in understanding information processing. This is done in the context of five experiments, each of which will now be summarized briefly. Much of this work is also described to varying degrees in Teichner's, 1979 article.

Experiment 1. Teichner's first experiment using the WiTS methodology manipulated two factors: The number of targets presented on the display and the duration the information was left visible on the display. Both of these factors were completely crossed. However each experiment session had a single condition presented in it. 1, 2, 4 or 8 digits were presented at random on a 4x4 cell matrix for 100, 200, 400 or 800 milliseconds (msec.). Responses were made on a 2 row by 3 column matrix of response buttons. The results of this study showed a systematic increase in total time, input time, the number of responses made and the number of correct responses with increases in the number of items to be identified. Duration that the display was on the screen was found to affect mainly the case where 8 targets were presented on the display, at which time there were far fewer responses, (correct and incorrect), and much shorter total and input latencies on the task with the shorter display durations. The important findings from this experiment were that:

---

[8]Case 4 can be somewhat problematic for the applied researcher because it is not unreasonable to expect that the occurrence of errors when both input and output are significantly affected by some variable would happen on a fairly frequent basis. There is however, a solution to this problem. Corso & Kelley (1983) and Morrison, Corso & Yuasa (1989) adopted a procedure whereby the input and output time measures are calculated only for those trials wherein all the relevant stimuli are identified correctly, and there are no extra responses. In this case, the issue of t/s is straightforward because $N_S = N_R$ in all cases. This approach, is in fact common to the subtractive and additive factor methodologies. For more discussion of the issue of N_S and what constitutes a distinct stimulus in the display, see Chapters 6 and 7 of this report.

1.1 Total time was qualitatively similar to input time showing similar effects with similar magnitudes of change. Output time was qualitatively different from both total and input time.

1.2 The loss of information in incorrect trials was attributed to processing on the input side because that is where the effects of display density and display duration were found. The t/s was therefore calculated on the basis of N_S.

1.3 Assessing t/r with and without the inclusion of movement times showed that regardless of the inclusion of movement times, t/r varied little and unsystematically with the factors manipulated in this experiment.

Experiment 2. This experiment represented a slight modification to experiment 1 because the order of conditions was randomized within each block, i.e. subjects did not know until after each trial was presented how many stimuli would be present. In addition, only the shorter display duration times (100, 200 msec.) were used. No significant t/r effects, nor t/s effects were found as a function of the number of stimuli presented on the display. The important conclusions from this study are:

2.1 When subjects could not anticipate the number of stimuli that would appear, they apparently adopted a slow, i.e., conservative rate of input as measured by t/s as a processing strategy. As a result, there were fewer responses made, correct or otherwise.

Experiment 3. This experiment was designed to assess the effects of display organization on input and output time. Teichner argued that the organization of elements on the display should purely affect input, and that this would be reflected by significant effects for input time, but not for t/r. The display used in this study consisted of a 2 row by 4 column matrix, in which all cells were filled with stimuli, i.e. display size had 1 level with eight elements. Display durations of 100, 200, 300, and 400 msec. were used. Major findings for this experiment were:

3.1 The total time required to perform the task depended in part on practice.

3.2 The number of responses made, and the number of correct responses depended on the display duration.

3.3 Neither input time or t/r were affected by the duration of the display.

3.4 Comparing the results of this study, (where the position of all the display elements would appear was perfectly predictable), to those of the earlier experiment, (where the position of the stimuli within the display matrix was unpredictable), showed that the predictable displays were faster as measured by total time and t/s when the display positions were predictable. Further, the t/r's for the predictable and unpredictable conditions were comparable, supporting the argument that display organization is a factor affecting input processing.

3.5 There were practice effects as measured by both t/s and t/r. However, these effects were different as a function of display organization. Input effects were non-linear, particularly with the more organized display where performance as measured by input showed an initial large loss in performance, from which it rapidly improved. Output showed a linear improvement as a function of practice regardless of the organization of the display. Again, this supports the proposition that organization in the display is an input variable.

Experiment 4. This experiment adapted Sperling's (1960) partial report procedure to the conditions used in experiment 3. In this study, a probe was given which (depending on the group) indicated which of the four (two element) columns were to be identified or which of the two (four element) rows was to be identified. The major findings of this study were that:

4.1 The use of a probe served to reduce total time required to complete the task, input time, and t/r.

4.2 The locus of the probe effect was found to be in input processing. Again, Teichner argues that this supports the utility of the WiTS methodology, because one would expect display

effects to be in input, as well as providing empirical support for the existence of a short-term storage (working) memory.

Experiment 5. Experiment 5 was yet another variation of the organization of stimuli on the display. In this study, all stimuli were presented within a 3x3 matrix on the display. However, the display matrix was presented entirely in central vision. Further, an aspect of the response side of the task was manipulated in order to assess its effects on input and output. This factor was whether labels were present or absent on the response panel buttons. Duration of the display and number of stimuli on the display were manipulated as well. The major results of this study were:

5.1 Neither the number of responses made, nor the number of correct responses, were affected by the presence or absence of labels on the response panel.

5.2 There was a display duration by stimulus density interaction for total time, input time and t/r which showed that the time per response increased when a large number of targets were presented, particularly when the presentation of those stimuli was brief. This is consistent with the findings of experiment 1.

5.3 The absence of labels was found to influence total time, and t/r. Further, there was an interaction between the presence and absence of response labels and the number of stimuli that were to be identified. This shows that at least some of the processing associated with the labels on the response panel occurs during output.

5.4 With regard to input time, this study showed that the removal of labels from the response panel <u>added</u> a constant to input time. However, there was no display density by label interaction. Therefore, it must be concluded that some processing of the response panel occurs during input.

5.5 The largest effect for response labeling was in output, as would be expected based on the definition of output.

In summary, Teichner's early studies using the WiTS method succeeded in showing the utility of both the concept of input and output and the operational definitions he generated to measure their duration. The locus of a number of significant effects was determined, and appropriate effects were found for both input and output. Exposure time of the display was shown only to affect input. This makes sense because "... regardless of stimulus persistence in sensory memory, the time that the stimulus is available must precede storage in non-sensory memory." (Teichner, 1977, p. 44). Density ought to affect input, assuming that input is at least in part a serial process. Density should also affect output given that the tasks used demand serial output by definition. This was found to be the case. Whether or not display density should affect t/r cannot be stated a priori, and was therefore treated as an empirical question. The results of Teichner's studies showed that when response uncertainty is high, t/r is affected by the number of stimuli which must be identified. Further, the results of these first WiTS studies demonstrated that the encoding for the response takes place during both input and output processing.

A final point that merits discussion, although Teichner does not explicitly discuss it, is the finding that the duration of the display did not affect t/s or t/r. Significant effects for the shorter duration displays were only found when eight stimuli were to be presented, and the only measures that were affected were the number of responses that were issued. If t/s is calculated in terms of N_R, neither t/s nor t/r were significantly affected by stimulus duration. This lends support to the viability of assumptions 2 & 3, because if input does not stop when output begins, it would be expected that removing the stimulus display prior to the end of input processing would cause t/s to be shorter relative to conditions where subjects have the display available as long as needed. Apparently, the short duration of the display when eight stimuli were present caused input processing to stop, and only those stimuli that had been processed from sensory memory to working memory were processed in output. Thus, t/s remained stable despite the changing display duration. These early WiTS studies provide support for two WiTS assumptions, i.e. 1) that input stops and

output begins when all the items to be stored in memory have been stored in memory, and 2) that at least some portion of input processing is serial in nature.

Despite Teichner's promising early results with the WiTS methodology, few researchers have employed it since it was initially proposed. There has been no criticism of the methodology presented in the literature. The failure to pursue the methodology may be attributed, at least in part, to Teichner's death shortly after his initial work with the WiTS technique was published. However, there are five additional studies using the WiTS methodology to date. These shall now be briefly reviewed here.

Williams (1977) assessed Stroop task phenomena in terms of its effects on input and output as defined by the WiTS methodology. Experiment I in her report described classic Stroop phenomena where there is an increase in the time required to identify colors when they are presented in the form of contradicting color names relative to the time required to identify color names when they are presented in achromatic color, (e.g. green letters used to spell the word RED versus the word RED printed in black). The study manipulated 1) the amount of information as defined by the number of relevant targets on a display to be identified, 2) the particular stimuli on the card, i.e. color names written in black, color names written in contradicting colors. Irrelevant stimuli on the displays took the form of rows of X's printed in either the same chromatic colors being used as relevant stimuli or achromatic color (black). Williams found classic Stroop (1935) effects as measured by total time, input time and t/r, wherein the Stroop conditions took longer to identify as measured by all three latencies. Further, she found that the more information in the display, the greater the total, input and t/r, as well as a significant coding by amount of information interaction as measured by t/r. Because both input time and t/r were affected by the coding (Stroop versus non-Stroop) manipulation, Williams concluded that both input interference and

output competition accounted for stroop phenomena. Thus, both input processing and output processing effects contribute to the Stroop effect.

A second study was reported by Williams (1977) wherein reverse Stroop phenomena was investigated. In this study, subjects identified the colors of the words and ignored the color names. Also, the response panel was labelled with achromatic color names, and patches of color to determine how response labelling affected input and output processing. The results of this study showed that Stroop type stimuli still took longer to process than non-Stroop stimuli as measured by total input and output time. However, the response panel labeling effect had a locus that was clearly in output processing as measured by t/r because the color names were significantly slower than the color patches as measured by this variable. Further, there was an interaction for t/r between response panel labeling and number of stimuli. Therefore, Williams concluded that while the Stroop effect is a product of both input and output processes, the majority of the effect is due to output.

The importance of the Williams (1977) study is that it confirms the basic results obtained by Teichner (1977) and further, demonstrates the utility of the WiTS methodology in assessing display coding and information processing issues. The utility of the WiTS methodology was directly compared to that of the additive factor method in a later study by Corso & Warren-Leubecker, (1982). This study modified the WiTS methodology so that the task could be directly compared to that of the binary classification task that is the basis of the additive factor method. Their results showed that effects that were masked in the analysis of the binary classification task were evident in the use of the WiTS methodology. On the basis of these results they advocated the use of the WiTS methodology in the study of human cognition.

Corso & Kelley (1983) also examined the results from a binary classification task in terms of the WiTS approach to response time partitioning. Again they performed two experiments. In the

first experiment, subjects were to identify the number of stimuli that appeared in the display. In addition, the stimuli to be identified were manipulated, and could either be "X"s or the word "INITIATE". Subjects were told to identify the number of relevant targets by pressing one of two response buttons, one of which designated that X's had been presented, the other of which designated that INITIATE stimuli had been presented. Subjects were also asked to perform the task using either their left or right hands. It was argued that, if there was a difference in the time required to identify the two types of targets, the effect should have its locus in input. Handedness, however should have its locus in output. The results of this study bore out the expected effects for input and output. In addition, the Teichner procedure was modified by using percent correct as a measure of performance accuracy, and eliminating the incorrect trials from the latency analyses. The results for accuracy showed that as the number of targets to be identified was increased, accuracy decreased.

A second experiment was performed in which a series of columns consisting of X's and O's were presented on the display sequentially. Subjects would either indicate the number of X's, by pressing one response button or identify the number of O's by pressing a second response button. The response button would be pressed to indicate the number of X's and O's depending on which was the relevant stimulus. The relevant stimulus was determined by a criterion based on the proportion of X's and O's that were in the column. When the number of X's met or exceeded the criterion set by the experimenter at the start of the trial, the correct response would be to press the X button once for each X that had been present in the column. When the proportions of X's was less than that specified by the experimenter, the subject was to identify the number of O's that had been present in the column by pressing the O button once for each O that had been in the column. An additional manipulation was introduced to see if processing could be interrupted by presenting an audio tone immediately after the first identification response had been given for a column on some number of trials. The results showed that:

1. Display load and the proportion of stimuli that are relevant to the task impact input time.
2. When the proportion of targets to non-targets was equal to .50, the task was the most difficult as measured by latency and accuracy.
3. Increasing the difficulty of the task through the manipulation of display load and the occurrence of task interference as the task is being performed impacts both input and output processing as measured by both latency and accuracy.
4. Evidence was found that suggested a shift in processing strategy as a function of the proportion of targets to non-targets in a display. This strategy affected both the rate of input and output as measured by the WiTS methodology.

The importance of the Corso & Kelley (1983) studies are that they: 1) utilize percent correct as a measure of performance accuracy, 2) assess input and output time only on the basis of correct responses, 3) attempt to use the WiTS methodology to assess the locus of such factors as handedness, target code type, and target processing strategy. The methodological modifications used in these studies are common to those in the Morrison, Corso & Yuasa study reported next, and the studies that will be described in the remainder of this paper.

Morrison, Corso & Yuasa (1989) were the next to use the WiTS methodology. They performed two studies which assessed how particular code types are processed, and also assessed the issue of code redundancy. The particular types of codes used were blocks of color and semantic codes, i.e. color names in their first study and animal names in their second study. They also manipulated display size. The relative performance was measured by response accuracy (percent correct), total time, input time per target (t/s) and output time per target (t/r). Their results showed that:

1) color blocks and redundant coding (names that were consistently mapped to the same color) were identified more rapidly that color names as measured by total time, input time per target and output time;

2) there was no difference in performance as measured by percent correct;

3) the linear relationship between the number of targets on the display and total and input time found by Teichner (1977, 1979) was confirmed; and

4) there was a significant interaction between the type of code used in the target and changes in total and input time per target.

These findings effectively confirm the results obtained by Williams (1977) by showing that there are code effects for code type in input and output. However, the bulk of the processing effect is in input. This study served to demonstrate the utility of the WiTS methodology, and the modification developed by Corso & Kelley in assessing the relative performance with alternative target coding, and further, succeeded in demonstrating the locus of those effects as being in input and output to differing degrees.

Rudolph (1992) obtained results for redundancy consistent with those found by Morrison, Corso & Yuasa. In his study he used the WiTS methodology to study the effects of contrast and numeric/spatial codes as well as the case where they were redundant and where one code was irrelevant to performing the identification task. The study used the same apparatus as that used by Morrison, Corso & Yuasa, which employed a four by four cell display and response matrix. The output time used by Corso & Kelley (1983) and Morrison, Corso & Yuasa was modified by dividing the time per response by the number of responses executed. The results indicated that there was no significant difference between the contrast and numeric coding of targets in an identification task. Further, significant differences were found for the presence of either the redundant or noise coding conditions. However, an unusual aspect of this experiment was manipulated in that a wide range of display density conditions were employed (2, 6, 10 and 14 of the 16 cells were filled with targets).

The results with regard to density indicated that processing strategy was adjusted when the target density exceeded 50%, and the non-target cells were identified rather than identifying the target cells. Rudolph concludes that the redundant stimuli do not significantly impact performance, nor does the presence of irrelevant (noise) codes.

Since the application of the WiTS methodology to date has been reviewed, it is now appropriate to consider how it will be applied in the research described in the remainder of this report. In the next four chapters a series of studies are described which assess the impact of different display and response mappings on percent correct, total time per target, input time per target and output time per target. In effect, these studies continue to use that variant of the WiTS methodology developed by Corso & Kelly, (1983) and Morrison, Corso & Yuasa (1989). Through manipulations to the particular requirements of the identification tasks performed, this research will assess:

1. How processing in the identification of two different, but conceptually similar categories of codes are processed in terms of the input and output processing defined by the WiTS methodology.
2. How the identification of codes from two very similar code categories presented together in the same display compares to the processing of those codes when they are presented in separate displays.
3. How the identification of codes collocated with irrelevant codes compares to the identification of those codes when they are presented without irrelevant codes in the display.
4. How the identification of multiple codes from a single target compares to the identification of those same codes when they are presented as single code targets.

5. The impact of code redundancy on input and output processing and how it compares to the identification of multiple, but non-redundant, codes, and the identification of a single code targets.

In addition to these display coding issues, a number of other issues will be addressed in the course of this paper:

6. The appropriate calculation of t/s shall be theoretically and empirically addressed in this with regard to the identification of codes versus targets in the context of the revised WiTS methodology used by Corso & Kelly, (1983); Morrison, Corso & Yuasa, (1989) and Rudolph, (1992).
7. The effects of alternative response panel mappings for performing the same identification task will be addressed in terms of input and output processing.

Chapters 4-7 describe a series of four studies which address the issues listed above. The next chapter will describe the particular experimental conditions and general methodology that serves as the basis for the studies described in Chapters 4-7. Chapter 8 will provide a general discussion of the findings of these studies, and their implications for both the WiTS methodology and the application of the findings of this research to the design of tasks.

(This page intentionally left blank)

CHAPTER 3 - General Approach and Method.

The questions identified in Chapter 2 will be addressed through a series of closely related studies which will require that a number of experimental conditions be defined that create variants on a common identification task. In order to answer these questions as efficiently as possible, a series of studies is described in the following chapters that will answer each question independently. Each of the analyses described in the following chapters, however, is based on subsets of experimental conditions for which data are collected at the same time. This approach will allow a single data set to serve multiple purposes, i.e. the answering of different but related questions regarding the processing of display and response codes in an identification task, and will also allow the generalization of results across the individual studies.

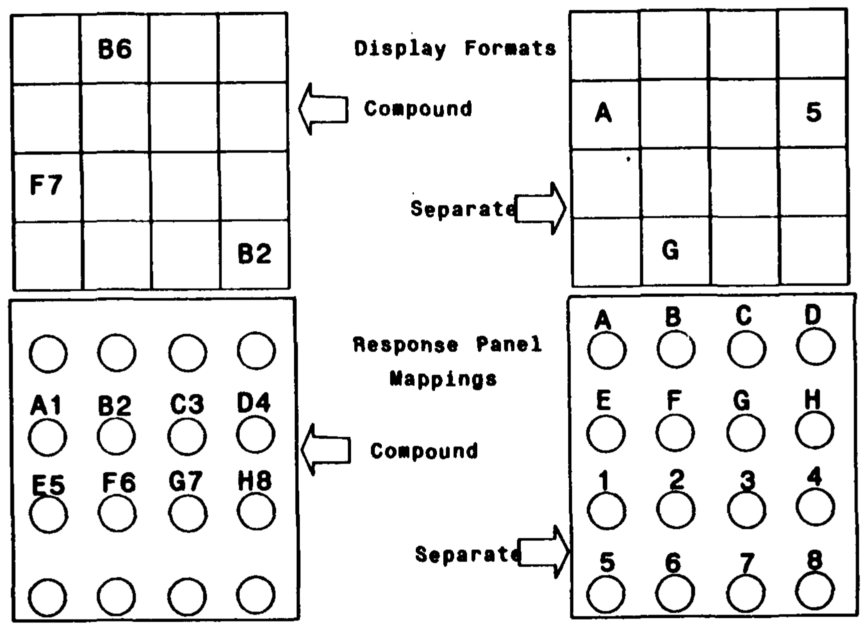
This chapter describes the general research methodology used in conducting the studies described in the following chapters. The general approach to this research was to identify a number of factors which, on a theoretical or empirical basis, should affect input and output processing as defined by Teichner's (1977, 1978) model. For the purposes of data collection, the individual studies described in Chapters 4, 5, 6 and 7 could be considered a single experimental design. This design is shown in Figure 3-1. As may be seen from the figure, there are a total of 13 between subjects conditions generated by crossing seven target-task manipulations with the two response mapping conditions[9]. Representative samples of the display and response panel are shown in Figure 3-2.

[9]Completely crossing the responses panel mapping condition with all levels of target-task would have generated a total of 14 between subjects conditions. However, the questions being asked with regard to the Redundant target-task condition, and the general approach of comparing only selected target-task, response panel mapping conditions to each other did not necessitate a completely crossed experiment design. See Chapter 6 for the analyses and discussion of the Redundant target-task condition for more details.

Figure 3-1. Experimental Conditions for study of the Effects of Display and Response Codes on Information Processing in an Identification Task.

Between Factors:			Within Factors:			
Target Codes	Task Instruction	Response Mapping	Number of Targets:	2	3	4
			Blocks:	1-10	1-10	1-10
Digits	Digits	Separate				
		Compound				
Compound	Digits	Separate				
		Compound				
Letters	Letters	Separate				
		Compound				
Compound	Letters	Separate				
		Compound				
Separate	Both	Separate				
		Compound				
Compound	Both	Separate				
		Compound				
Redundant	Both	Compound				

Figure 3-2. Sample Display formats and Response Panel Mappings.



The target-task manipulation describes two aspects of the identification task. The target in the target-task manipulation refers to the specific target codes presented on the visual display used in this research. The display used was a four-by-four cell matrix in which some number of cells are randomly selected to have targets placed in them. When digits are presented as target codes, subjects see a single digit code presented in each of the selected target cells. When letters are presented as target codes, subjects see a single letter code presented in each of the selected target cells. Compound targets consist of a digit-letter combination of codes that are presented immediately adjacent to each other in the selected target cells, (multi-code targets). The redundant target codes are similar to the compound codes in that they consist of a digit-letter combination placed immediately adjacent to each other. However, they have the added property that the same digit is always presented in combination with the same letter. The final target code condition is the separate targets condition wherein a single letter or digit code may be presented in a cell, with the result that both digits and letters may appear on the display, but there is a single code in each filled cell.

The task aspect of the target-task manipulation refers to the instructions given to the subject regarding what aspect of the targets is to be identified. The digits-instruction was used to tell subjects to identify only the digits presented on the display and, if letters are present, to ignore the letters. Likewise, the letters-instruction means that subjects are to identify only the letter targets on the display and, if digits are present, to ignore the digits. When instructed to identify both codes in the target, subjects are told to identify both the digits and letters presented on the display.

The target-task conditions which result from the combining of the five levels of target type with three levels of task instruction will be denoted as follows:

Digits - The digits condition will have a single digit cell presented in each of the 2, 3 or 4 cells that have targets. The particular codes used in any target will be randomly selected from the set: 1, 2, 3, 4, 5, 6, 7 and 8. Subjects will identify all targets presented on the display.

Compound (Digits) - The compound (digits) condition will have a digit-letter (or letter-digit) in each of the 2, 3 or 4 cells on the display that have targets. The codes used will be randomly selected from the digits and letters sets. Subjects will be instructed to only identify the digit codes.

Letters - The letters condition will have a single letter code presented in each of the 2, 3 or 4 cells that have targets within the 16-cell display matrix. The letters will be randomly selected from the set: A, B, C, D, E, F, G and H. Subjects will identify all targets on the display.

Compound (Letters) - The compound (letters) condition will use digit-letter or letter-digit combinations comparable to those used in the (compound) digits condition, however subjects will be instructed to identify only the letter codes on the display. The codes used will be randomly selected from the same sets used for the digits and letters conditions.

Separate - The separate target-task condition will have a single letter or digit code presented in each of the 2, 3 or 4 cells that are filled in the display. The codes will be randomly selected from the set: A, B, C, D, E, F, G, H, 1, 2, 3, 4, 5, 6, 7 and 8. Subjects will be instructed to identify all the digits and letters that are presented in the display matrix.

Compound - The compound target-task condition will use the same digit-letter or letter-digit combinations used in the (compound) digits and (compound) letter conditions. However, subjects will be instructed to identify all the digit and letter codes presented in the 2, 3 or 4 target cells[10]. The codes used will be selected from the same eight letter and 8 digits sets used in the other conditions.

Redundant - The redundant target-task condition uses letter-digit and digit-letter conditions similar to those seen in the compound target-task condition, except that the digits and letters will be mapped so that the same digit always appear with the same letter. The targets used will be randomly selected from the set: A1, B2, C3, D4, E5, F6, G7 and H8. Subjects will be instructed to respond to both the digits and the letter code presented in each of the 2, 3 or 4 filled target cells[2].

The other between-subject manipulation is response mapping. Response panel mapping refers to how the target codes are assigned to buttons on the response panel. In this research target codes are assigned to the response panel using either of two basic schemes. The separate response mapping has a single letter or digit code assigned to each response panel button. The compound response mapping has two codes assigned to each response panel button, one of which is always a digit and one of which is always a letter.

Two within-subjects manipulations are shown in Figure 3-1. They are completely crossed with each other. The number of targets manipulation refers to the number of cells in the four-by-four cell matrix which have target codes in them. There could be targets in either two, three or four

[10]It should be noted that both the Compound and Redundant conditions require twice as many actual response as the other target-task conditions because there are two codes per target being identified. This aspect of the design should not make the analysis of latency data problematic because all latency measures are converted to time per target measures, as described in Chapter 2.

of the cells in the 16-cell display matrix. There are ten blocks of trials for each subject in the thirteen between-subjects conditions. Each block consists of ten trials for each of the three levels of number of targets to be identified. Thus, with ten trials for three levels of number of targets to be identified, there were thirty trials per block, and a total of 300 trials for each subject. Each block of practice is separated by a brief break, the duration of which was controlled by the subject. Longer breaks were forced by the experimenter after blocks 3 and 7.

METHODS

Apparatus. A generic MS-DOS based personal computer using a 25 Mhz Intel 386 processor was used to run the experiment and collect all data. A generic 13-inch color video display was used to present the display formats. The display was driven by a Paradise VGA graphics card adapter using standard display fonts. A single display format was presented on the display for each trial. This format consisted of a 4x4 cell matrix with each cell measuring 1-½ inches on each side. Two, three or four of the cells were filled with the Paradise text-mode alpha-numeric symbols. Display intensity was adjusted for comfortable viewing and held constant throughout the experiment. Targets within the display consisted of either digit symbols, letter symbols, or for compound target conditions, a digit and letter symbol presented adjacent to one another. In the compound targets either a digit could appear first followed by a letter, or a letter first followed by a digit. The relative position of letters and digits in compound targets were counterbalanced across subjects such that subjects saw either the digit-letter or letter-digit combination, when they were in a compound target condition, but not both.

Responses were made using a custom built response panel. The response panel consisted of sixteen, ½-inch round, momentary push-buttons. The buttons (Radio Shack catalog number 275-609) were arranged in a 4x4 square matrix on 1-½ inch centers. A seventeenth, ½-inch, square, button (Radio Shack catalog number 275-618) was placed 1-½ inches below the bottom of the matrix, and 3-inches from either edge. This square button served as a "home" key that subjects pressed to start and end each trial. The home key was held until subjects began responding. These buttons were interfaced to the 386 computer through a Scientific Solutions LabTender laboratory interface card

operated with custom written software, which may be found in Appendix 1. This interface served as the basis for timed and decoded button presses with millisecond resolution.

Response buttons were labeled using ¼-inch, white, helvetica medium, vinyl lettering (Chartpak number 01006) applied to movable flat-black, foam core panels. These panels were applied as appropriate to the particular experiment condition being run for a given subject. All sixteen of the response buttons were labeled in the separate response mapping conditions, with a single code assigned to each button. The arrangement of codes on the buttons was to place either letters on the top two rows of buttons and digits on the bottom two rows, or vice se versa, counterbalanced across subjects. Only the middle two rows of four buttons were each employed in the compound response mapping conditions. As with the compound targets in the display, the compound response labels could be labeled with a letter-digit (A1, B2, C3, D4, E5, F6, G7, or H8) or digit-letter (1A, 2B, 3C, 4D, 5E, 6F, 7G, or 8H) combination. The letter-digit, digit-letter combination was counterbalanced across subjects employed in the compound response mapping conditions. When subjects were in a condition with both compound display and response codes, the letter-digit, digit-letter counterbalance was kept consistent across the display and response codes. Response codes were arranged in alphabetic or increasing numeric order, as shown in Figure 3-2.

The response panel was tilted toward the subject at an angle of 30° from horizontal. The display was mounted immediately above the response panel and was tilted down 10°, as shown in Figure 3-3. Subjects sat approximately 8-12 inches from the front of the response panel.

The experiment test room was a 4x6 foot sound-proofed chamber. The chamber was lit by a 15 watt, ceiling mounted fluorescent light, located above and behind the subject. The chamber was also equipped with a fan for air circulation and a closed-circuit television camera. The closed-circuit television system allowed subject performance to be monitored by the experimenter throughout the

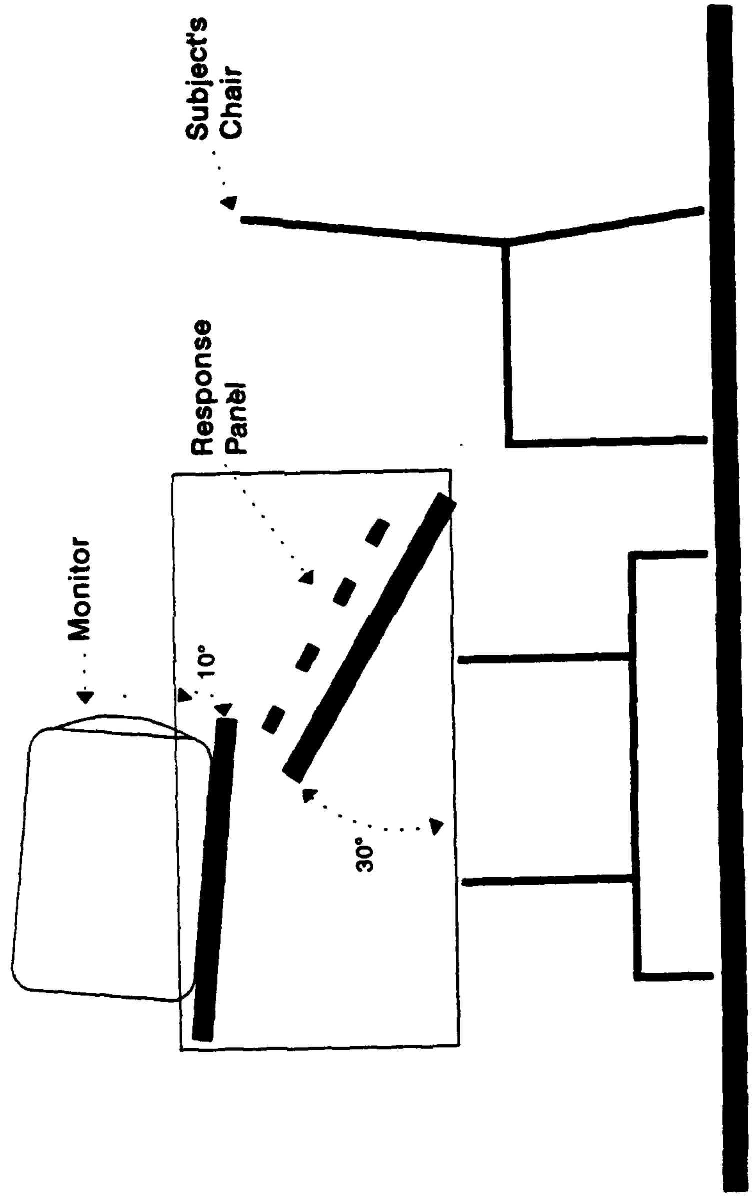


Figure 3-3. Subject's Experiment Station.

course of the experiment.

Subjects. A total of 132 subjects were run in the experiment to obtain ten subjects for each of the 13 between subjects groups. Subjects were male volunteer undergraduate students attending classes at the Georgia Institute of Technology, School of Psychology. All subjects retained for the experiment had normal (20/20 corrected) vision and were right handed. Two subjects were run, but their data discarded because they were left handed. Subjects received class credit as compensation for their participation in the experiment. An additional subject was omitted from the final data analysis because he performed the task incorrectly by using the wrong rows of response buttons.

Procedure. All subjects were solicited through an announcement posted on a School of Psychology bulletin board. When subjects arrived for their experiment session, they were briefed on the experimental task and asked to sign a consent form. The task subjects were to perform was then demonstrated by the experimenter to familiarize them with the task. Subjects were then given the opportunity to ask questions regarding the experiment. The script used for the subject briefing is included as Appendix 1.

Subjects were instructed to identify their targets as accurately and quickly as possible. Subjects were allowed to pace their way through the experiment. This was done by pressing and holding the "Home" key at the bottom of the response panel when they were ready to begin a trial. Subjects were given the opportunity to take a brief rest before the start of each trial. Immediately after each trial the message: "**Done timing this trial. If you would like to take a break release the bottom button within the next three seconds.**" would appear on the display. The experiment would stop if the button was released during this period. All buttons were to be pressed using only the right index finger. Subjects were instructed that once they began identifying targets they were to

continue identifying all targets as quickly and accurately as possible until all targets were identified. When they completed identifying all targets, subjects again pressed the home key to end the trial.

At the start of each trial a target matrix would appear after a random wait for three to five seconds. Once the display appeared, it would stay on the screen until the subject lifted his finger from the home key, or until a maximum time had been reached. The maximum time a display would remain on the screen depended on how many targets were being displayed. The target matrix appeared a maximum of 5, 7.5 or 10 seconds for 2, 3, or 4 targets respectively. The maximum matrix duration was similar to that used by Teichner (1977, 1978) and Morrison, Corso & Yuasa (1988). Subjects also had a maximum time in which to make all their responses. This maximum response time was a function of the number of targets to be identified, and was based on preliminary data obtained by Morrison, Corso & Yuasa (1988). The maximum response time was 15, 22.5 or 30 seconds for 2, 3 or 4 targets respectively.

Dependent Measures. The software written to conduct the experiment recorded all the information necessary to measure response accuracy and latency for each response from the start of each trial. After the data were collected, post-processing software was used to determine if a trial had been responded to correctly. A correct trial was defined as a trial where all the targets that were to be identified were, and the only responses made were those for the targets present. Any trials for which there was a mechanical error, or during which there was some procedural anomaly was excluded from further analysis. When a trial was correctly identified, the total response time was defined as the time required to complete the trial measured in milliseconds. In addition, the time between the start of the trial and the first response, and then the elapsed time between each of the succeeding responses were determined. As per WiTS methodology, output time per target for each trial was calculated as the average of the time required for the second through final responses on any given trial. Input time for a trial was calculated by taking the time required from the start of

the trial to the first response, and subtracting the calculated output time. Input time per target and total time per target were calculated by dividing the input and output time measures by the number of targets that had been identified on that trial. A single estimate for four dependent measures was generated for each of the three levels of target density, for each block of practice. The dependent measures were: the percent of trials correctly identified, mean total time per target, mean input time per target, and mean output time per target. These data were then recorded in a format suitable for statistical analysis along with information indicating which between subjects group it had come from. This data set served as the basis for the analyses described in the next three chapters.

(This page intentionally left blank)

CHAPTER 4 - Identification of Single Code Targets from One or Two Code Categories.

This chapter summarizes the results from the first of a series of experiments based on the general experiment design and procedure described in Chapter 3. The study utilizes three target-task conditions in which each target consists of one code, which is selected from either of two code categories, or both categories. The general goal of this experiment was to assess whether the input and output processing in the two categories was different, as well as to determine how the input and output processing for identifying targets from both categories compared to that for identifying targets from each of the categories separately. Specifically, this goal translated into assessing input and output processing with the digits, letters, and separate (digits and letters in separate targets) conditions described in Chapter 3.

The basic objectives in conducting this study included:

1. Demonstrate the utility of the Within-Task Subtractive (WiTS) methodology in assessing performance in an identification task. In particular, demonstrate the utility of interpreting performance in identifying different categories of code symbols in terms of input and output processing.

2. Assess whether digits and letters should be considered different categories of code symbols, or a single code category, based on their relative performance in terms of input and output in an identification task.

3. Assess the impact of alternative response mappings on performance in an identification task, and consider the performance and processing effects of response mappings in terms of input and output.

4. Provide an empirical basis from which to generate hypotheses for study in later experiments, as well as to provide an empirical basis for the interpretation of the results obtained in those studies.

These objectives were accomplished in the context of a task that required the identification of single code targets from one or two code categories. Four dependent measures were employed in this study: overall identification accuracy, mean response latency, as well as mean input time per target and mean output time per target. Four factors were assessed: 1) the specific nature of the targets used in the identification task were manipulated (as determined by the code categories used), 2) the particular response mapping used by the subjects, 3) the number of targets presented on the display were all manipulated and 4) changes in performance across blocks. The manipulation of these four factors in combination facilitated meeting the objectives listed above.

In addition to meeting these general objectives, several specific research questions motivated the design of this study. One was: Is the performance seen identifying digits and letters comparable? As pointed out in Chapter 1, a variety of researchers have presented data which suggest that while digits and letters are often treated as a single alphanumeric code category, they may in fact represent distinct code categories (e.g. Pashler & Baylis, 1991[a,b]; Proctor & Fober, 1988; Briggs, 1974; Egeth, Marcus & Bevan, 1972; Dick, 1969).

Another question motivated the design of this study, and is carried through the studies in each of the following chapters. That question was: Does the mapping of multiple responses onto

single response keys change performance relative to the mapping of one response to each response key? This question stemmed from two sources. First, there is the increasingly common use of multi-function keyboard layouts in a variety of computer and commercial applications, and the ever increasing complexity of those layouts as software becomes more and more complicated (Shneiderman, 1987; Brown, 1989). Second, there is a lack of data regarding the effects that response mapping may have on processing, and the apparent interaction of task context with response requirements in affecting different aspects of processing. (See Chapter 1 of this report, Pashler & Baylis, 1991[a,b]; Proctor & Fober, 1988; Larish, 1986; and Hendrikx, 1986.) No research has been done to date which specifically attempts to isolate the effects of alternative response mappings in terms of input and output.

A number of hypotheses can be offered on an intuitive basis with regard to the identification of two categories of code symbols within a single task. It may be that the performance seen will be an average of the performance seen with the individual codes. This finding would suggest that the time required to identify all targets in a display does not involve category processing per se, but rather constitutes a sum of the times required to process each target individually in the display. Alternatively, it could be argued that performance with two categories of codes will be comparable to the worst performance with each of the separate code categories (Morrison, Corso & Yuasa, 1987; Rudolph, 1992). Such an argument would presuppose that the differences in processing reflect optimized strategies for processing a particular code category, and the strategy employed in processing tasks with both codes would have to accommodate the less efficient of the strategies. Finally, it could be argued that processing of the hybrid display with two categories of codes embedded in it will lead to performance that is worse than that found with either of the component codes. This argument could be based on either of two premises. First, if processing differences between the two code categories are the product of the number of elements in the category (e.g. 10 digits, or 23 letters), then the performance seen by combining these code categories in a single

display is the sum of the times required for all the symbols known by the subject as belonging to each of the categories that are present. The second premise that could explain why processing a display with codes from two categories could be worse is that an alternative strategy must be adopted for the encoding and identification of the two codes when they are together as compared to when they are processed separately, and the new strategy is not optimal for any one of the code categories present in the display.

This research was not intended to definitively identify the processes which led to differences in the identification of different information codes. Rather, it was intended to establish how the identification of targets consisting of elements from two categories of codes compared to the identification of those codes separately. On the basis of the empirical results, the mechanisms that may have generated those results could then be speculated on.

DESIGN

The first factor manipulated was the type of target presented in the identification task. Figure 4-1 shows that there were three levels of target type assigned as a between-subjects factor. Subjects could identify targets consisting of digits, with one digit symbol in each of several cells, letters, with one letter symbol in each of several cells, or a combinations of digit and letter symbols across several cells of the display (the separate condition). As described in Chapter 3, the cells were arranged in a four-by-four cell display matrix. In addition to the digits-letters-separate manipulation, two response mappings were employed as a between-subjects factor. The separate response mapping had a unique alphanumeric code associated with each response button. As described in Chapter 3, letters were on the top half of the 16 button response panel and digits on the bottom half of the response panel for half of the subjects, while for the other half of the subjects letters would be on the bottom half of the response panel, and digits on the top. All digit and letter codes were mapped with an ascending, ordinal mapping. The second response mapping, referred to as the compound mapping, had two codes, a digit and a letter, assigned to each of eight response buttons within the response panel. For half the subjects the buttons were labelled with digit-letter combinations, while buttons were labelled with letter-digit combinations for the remaining subjects. Again, the digit and letter codes were assigned with an ascending, ordinal mapping. The identification task used in this study required that all targets presented on the display be identified.

Two manipulations were assessed by the experiment design as within-subjects factors, (Figure 4-1). The first represents a manipulation of task load, defined by the target density. In this experiment either 2, 3 or 4 targets were presented within the 16-cell matrix on the display. The final factor assessed was number of blocks. Each block represented 30 trials (10 for each of the 2, 3 and

Figure 4-1. Experimental Design for the Digit, Letter, Separate Comparison.

			Within Factors		
		Number of Targets:	2	3	4
Between Factors	Target-Task Type	Response Mapping	Blocks: 1-10	1-10	1-10
	Digits	Separate			
		Compound			
	Letters	Separate			
		Compound			
	Separate	Separate			
		Compound			

4 target conditions). There were 10 blocks of trials for each subject.

The experiment design was a split-plot factorial with two between-subjects factors (target type and response mapping, at three and two levels respectively), and two within-subjects factors (number of targets and blocks, at three and ten levels respectively). This experiment represented the data for 60 subjects (10 subjects for each of the between subject conditions). Data for two dependent variables, percent correct for each block of trials, and response time for each response was collected. From the response time data, total response time per target, input time per target, and output time per target were calculated using the WiTS methodology, as described in Chapter 3.

The following predictions were described in terms of accuracy, total, input and output time.

1. There will be significant differences in the performance as measured by percent correct and/or time dependent measures for the digit-letter conditions. Since the strategies and/or mechanisms that generate these directions these differences take will not be speculated on a priori, the hypotheses are non-directional. It is also uncertain if the difference seen will be reflected by total, input and/or output time.

2. If the identification of a composite category (e.g. the *separate* task condition of digits and letters) proved to have different performance from the identification of component categories (e.g. digits or letters), then use of composite categories imposes additional processing demands from those of the component categories. The change in processing may be due to the processing of additional codes, or due to qualitatively different processing.

2a. If the composite code set had performance that was at least twice as bad, i.e. less accurate and slower, than that seen in either of the component categories, then the change in performance was due to the processing of additional codes in a larger target set.

2b. If the performance of the composite code set had performance that was approximately that of equal to the worst of the two component codes, then the performance seen in the composite code represented a qualitative change in processing, i.e. was due to a change in strategy.

2c. If the performance of the composite code set was approximately the arithmetic average of that seen in the independent code sets, then only those targets explicitly included in the display were affecting processing, and those codes that are not on the display are not affecting processing. This hypothesis is suggested by Briggs' (1974) suggestion that even though equivalent numbers of codes are used in the different target-task conditions, the use of well learned symbol sets, such as digits and letters, may mean that the entire set of codes (e.g. all ten digits and all 26 letters) may be transferred to working memory from long-term memory. If this were the case, then the processing of letters would be considerably more demanding than that for digits, and this would be reflected by the processing time for digits and letters.

3. If response mapping affected the way the identification task was performed then there will be differences in performance as measured by percent correct and/or total time as a function of the response mapping manipulation.

4. It was expected that all dependent measures will show a stereotypic learning curve over blocks. Specifically, performance will improve (increase in percent correct; decrease in total, input and output time) with increases in number of blocks. Further, the effect is expected to be non-linear, with the greatest improvement in the first few blocks. No

differential learning effects were predicted for the various target-task and response mapping conditions.

5. If the amount of information in a display affected the way information was processed, then a significant main or interaction effect involving the target density and one or more of the dependent variables would be found.

6. If the response mapping affected the way people read a display and encoded information into memory, then a significant main or interaction effect for input time and response mapping would be found.

7. If the response mapping affected the way information was taken from memory and translated to a response, then there would be a significant main or interaction effect involving output time and the response mapping.

RESULTS

The comparison of the various target and response panel manipulations was performed through a series of multi-variate analysis of variance (MANOVA) procedures. All MANOVAS were performed using the Complete Statistical Software (CSS: Statistica) analysis package for MS-DOS computers (Statsoft, 1991). Post-hoc comparisons for significant effects were performed using the Neuman-Keuls procedure (Kirk, 1982; Statsoft, 1991) included as part of this statistical software. A separate MANOVA was performed for each of the dependent variables: Percent Correct, Total Time, Input Time, and Output Time. The results of these analyses are summarized in Table 4-1 and are described below.

Percent Correct. There was one significant effect in the percent correct data in the analyses for the Digits-Letters-Separate comparison, as shown in Figure 4-2. This was for the number of targets main effect ($F = 12.4$, (2,106), $p < .01$). This effect resulted because the accuracy was significantly lower when there were four targets to be identified (95.2%), than it was when there were two or three (97.6% and 97.0%, respectively). The difference in performance was relatively stable across all blocks. The very high level of accuracy across all conditions suggests that the sensitivity of the percent correct measure is probably reduced due to a ceiling effect.

Total Time. There were significant total time main effects for the digits-letters-separate comparison ($F = 12.0$, (2,53), $p < .01$), target density ($F = 980$, (2,106), $p < .01$), and blocks ($F = 35.6$, (9,477) $p < .01$). These results, illustrated in Figure 4-3, reflect the separate targets (3645 msec. per target) taking 878 msec. longer on average to identify than digits (2767 msec.) and 266 msec. longer than letters (3379 msec per target). Letters did not take significantly less time per target than the digits

TABLE 4-1. Summary of MANOVA results for Digits-Letters-Separate. [30] [31] [32]

EFFECT:	% CORRECT:	TOTAL TIME:	INPUT TIME:	OUTPUT TIME:
Condition (C)	F=1.79(2,53) p = .177	F=12.0,(2,53) p < .01	F=4.59 (2,53) p < .05	F=14.3,(2,53) p < .01
Response (R)	F=2.49,(1,53) p = .120	F=0.09,(1,53) p = .771	F=0.64(1,53) p = .426	F=0.02,(1,53) p = .876
C_R	F=0.05,(2,53) p = .948	F=0.32,(2,53) p = .726	F=0.10,(2,53) p = .901	F=0.36,(2,53) p = .697
Targets (T)	F=12.4,(2,106) p < .01	F=980,(2,106) p < .01	F=443,(2,106) p < .01	F=31.7,(2,106) p < .01
C_T	F=0.29,(4,106) p = .814	F=9.73,(4,106) p < .01	F=1.92,(4,106) p = .112	F=6.91,(4,106) p < .01
R_T	F=2.17,(2,106) p= .119	F=1.05,(2,106) p = .352	F=0.18,(2,106) p = .836	F=15.1,(2,106) p < .01
C_R_T	F=1.06,(4,106) p = .379	F=0.97,(4,106) p = .429	F=0.14,(4,106) p = .967	F=5.61,(4,106) p < .01
Block (B)	F=0.90,(9,477) p = .525	F=35.6,(9,477) p < .01	F=6.93,(9,477) p < .01	F=32.9,(9,477) p < .01
C_B	F=0.66,(18,477) p = .853	F=1.03,(18,477) p = .421	F=1.17,(18,477) p = .283	F=1.62,(18,477) p = .051

[30] Condition (C) refers to the target-task conditions used in this analysis. Response (R) refers to the response panel mapping effect. Targets (T) refers to the number of targets being identified. Block (B) refers to the number of blocks of practice. Interaction effects are denoted by the abbreviation for the effects separated by an underscore, e.g. C_R indicates the Condition by Response mapping interaction.

[31] Analysis uses {Digits-Digits-Separate, Digits-Digits-Compound, Letters-Letters-Separate, Letters-Letters-Compound, Separate-Both-Separate, Separate-Both-Compound} as groups.

[32] Table based on revised analyses - March 7, 1992.

R_B	$F=1.23,(9,477)$ $p = .278$	$F=1.41,(9,477)$ $p = .180$	$F=1.83,(9,477)$ $p = .060$	$F=1.06,(9,477)$ $p = .389$
C_R_B	$F=0.81,(18,477)$ $p = .684$	$F=1.24,(18,477)$ $p = .227$	$F=2.80,(18,477)$ $p < .01$	$F=0.77,(18,477)$ $p = .734$
T_B	$F=0.90,(18,954)$ $p = .582$	$F=3.05,(18,954)$ $p < .01$	$F=0.61,(18,954)$ $p = .896$	$F=1.46,(18,954)$ $p = .095$
C_T_B	$F=1.01,(36,954)$ $p = .457$	$F=1.28,(36,954)$ $p = .130$	$F=1.29,(36,954)$ $p = .121$	$F=1.02,(36,954)$ $p = .432$
R_T_B	$F=0.84,(18,954)$ $p = .649$	$F=0.52,(18,954)$ $p = .950$	$F=0.65,(18,954)$ $p = .863$	$F=0.86,(18,954)$ $p = .632$
C_R_T_B	$F=1.29,(36,954)$ $p = .116$	$F=0.79,(36,954)$ $p = .804$	$F=0.76,(36,954)$ $p = .847$	$F=0.84,(36,954)$ $p = .729$

Figure 4-3. Digits, Letters, Separate:
Total Time

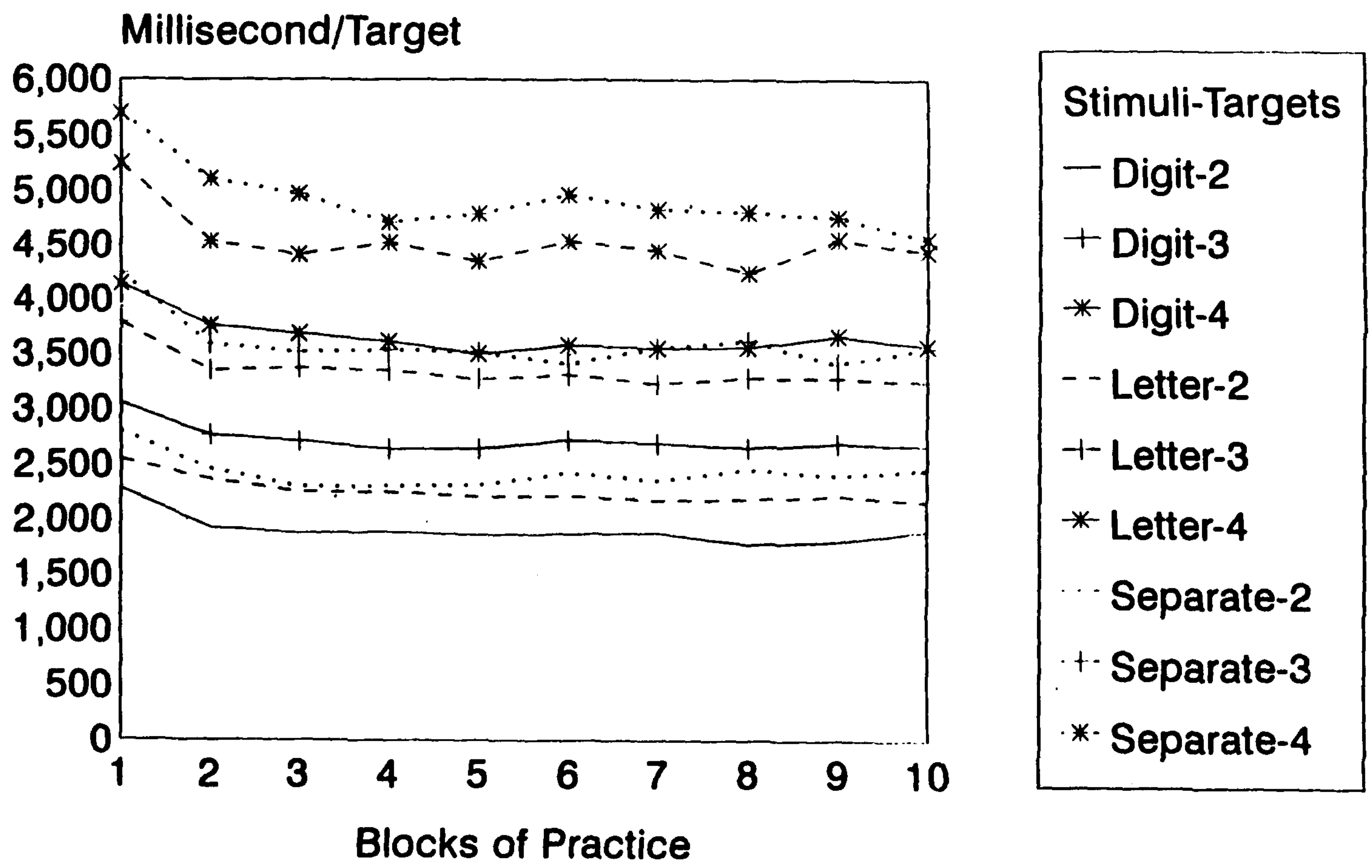
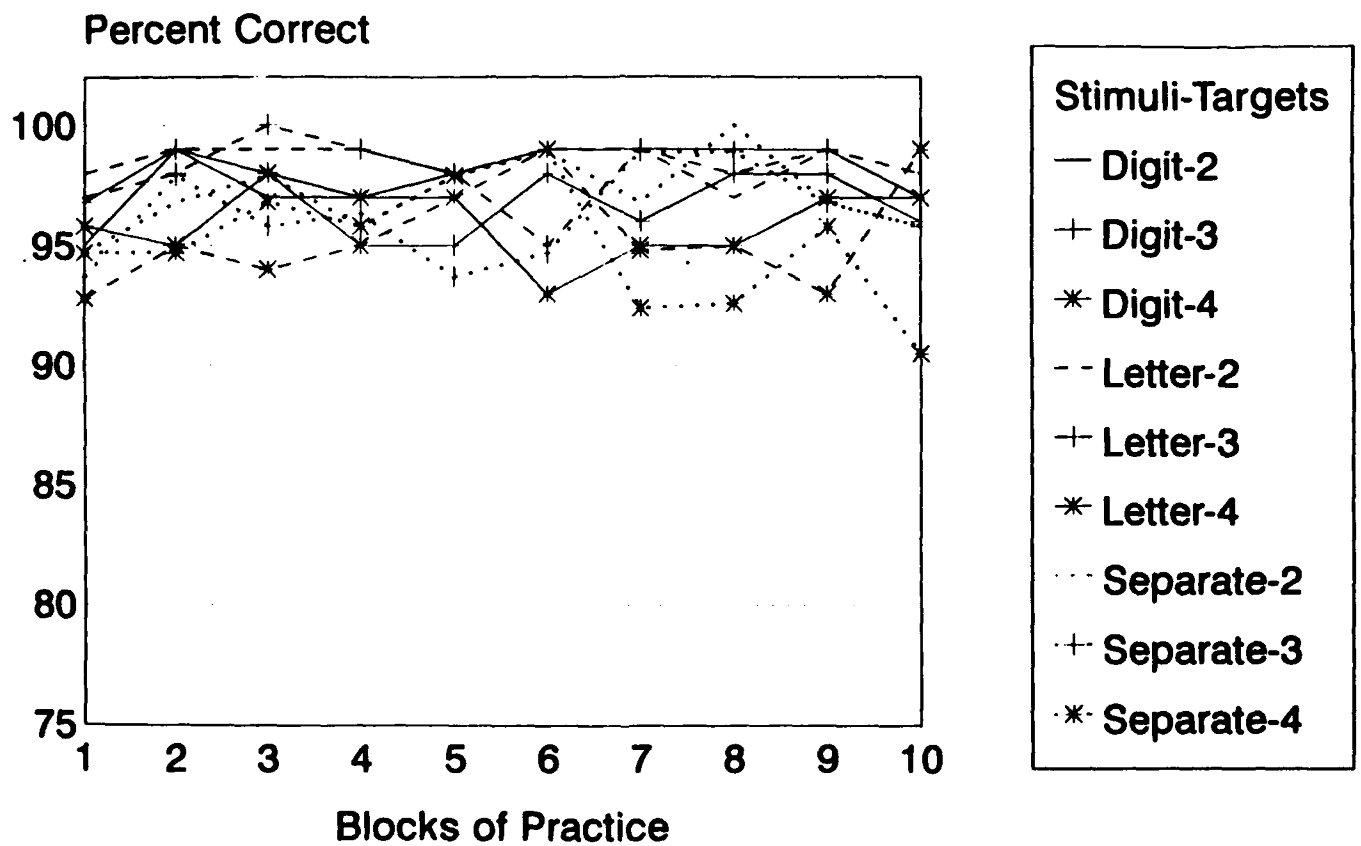


Figure 4-2. Digits, Letters, Separate:
Percent Correct



and letters (separate targets) in the post-hoc comparison. The overall time per response was longer for those conditions which had more targets to be responded to, i.e. the rate of responding was slower for the higher target density conditions (2200, 3223, 4368 msec. per target for the 2, 3 and 4 target conditions). Finally, response time decreased with blocks. Overall there appears to have been a substantial improvement through the first three blocks, and a modest improvement through the final seven blocks. The first block of trials required an average of 3747 msec. per target, while the fourth block had a total response time of 3195 msec. per target and trials in block 10 required an average of 3168 msec. per target. Thus, there was a 579 msec. per target improvement in performance throughout the course of the experiment. However, this was moderated by a density by blocks interaction described below.

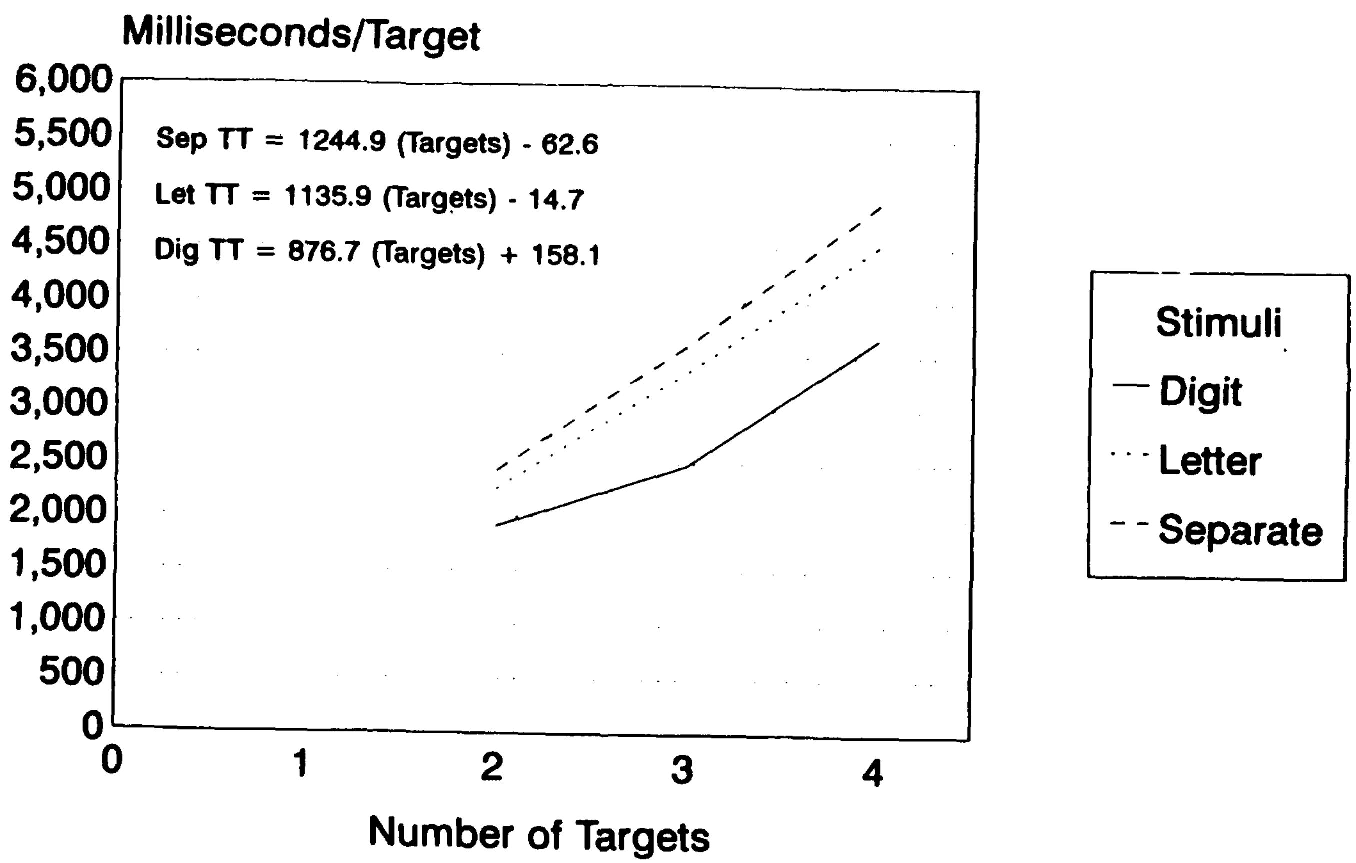
The highest order interactions found were two-way interactions for the digits-letters-separate comparison by target density ($\underline{F}=9.73$, (4,106), $p < .01$), and density by number of blocks ($\underline{F}=3.05$, (18,954), $p < .01$). The first interaction reflects the time required per target increasing significantly more for the letters (1136 msec. per target^2) and separate (1245 msec. per target^2) conditions, than it did for the digits condition (877 msec. per target^2), as shown in Figure 4-4, and described by the linear regressions:

$$\text{Total Time}_{\text{Digits}} = 876.7\,(\text{Number of Targets}) + 158.1$$
$$\text{Total Time}_{\text{Letters}} = 1135.9\,(\text{Number of Targets}) - 14.7$$
$$\text{Total Time}_{\text{Separate}} = 1244.9\,(\text{Number of Targets}) - 62.6.$$

The second interaction, block by target density, reflects a decrease in the time required to perform the task through first three blocks, and the reduction in total time per item was greater when there were more targets to identify.

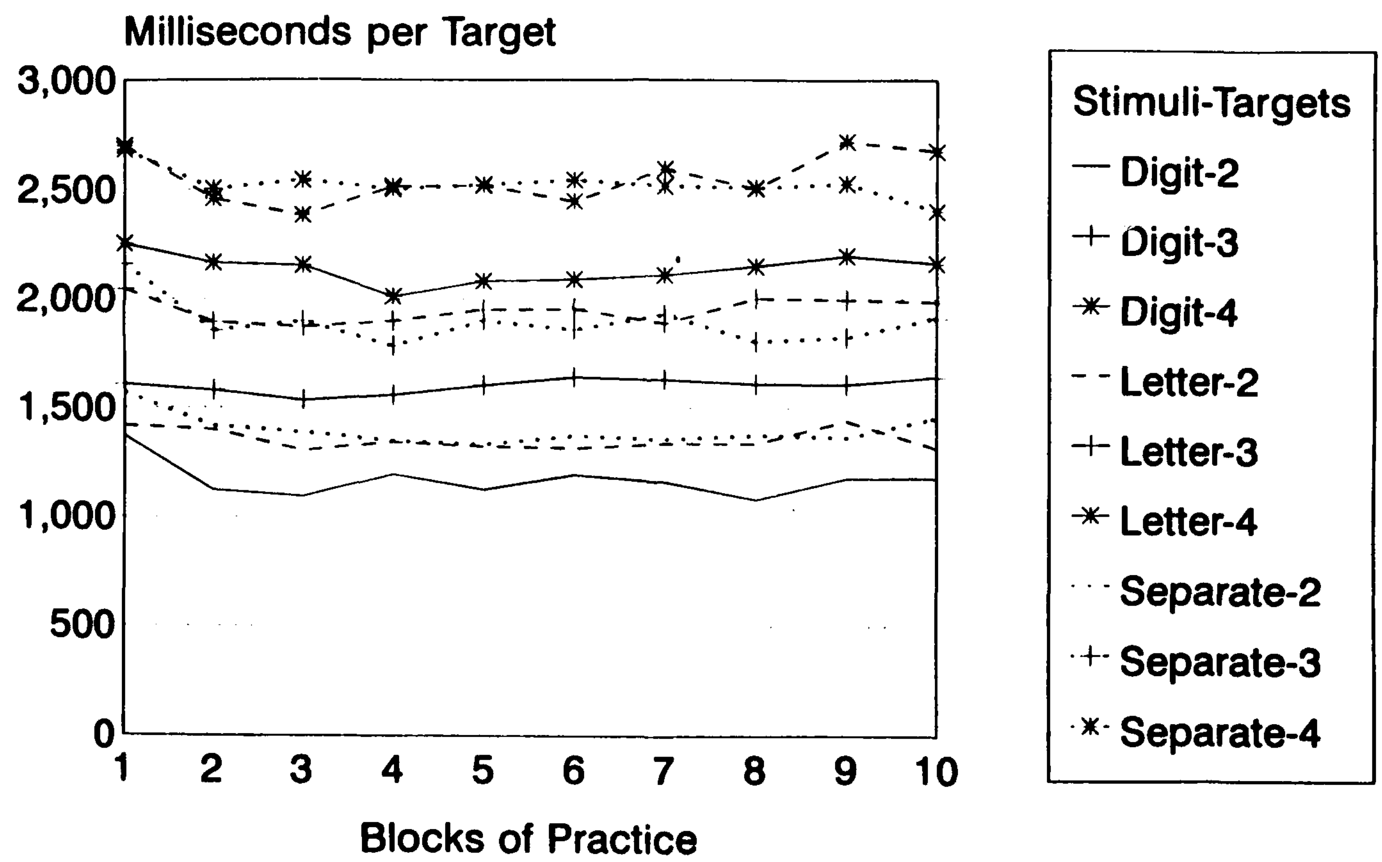
Input Time. Examination of the input time per target (Table 4-1, Figure 4-5) showed that there were significant main effects for the digits-letters-separate comparison ($\underline{F}=4.59$, (2,53), $p < .05$), number of targets ($\underline{F}=443$, (2,106), $p < .01$) and blocks ($\underline{F}=6.93$, (9,477), $p < .01$). As with the

Figure 4-4. Digits, Letters, Separate:
Total Time - Stimulus-Task by Number of Targets Interaction.



7 March 1992

Figure 4-5. Digits, Letters, Separate: Input Time

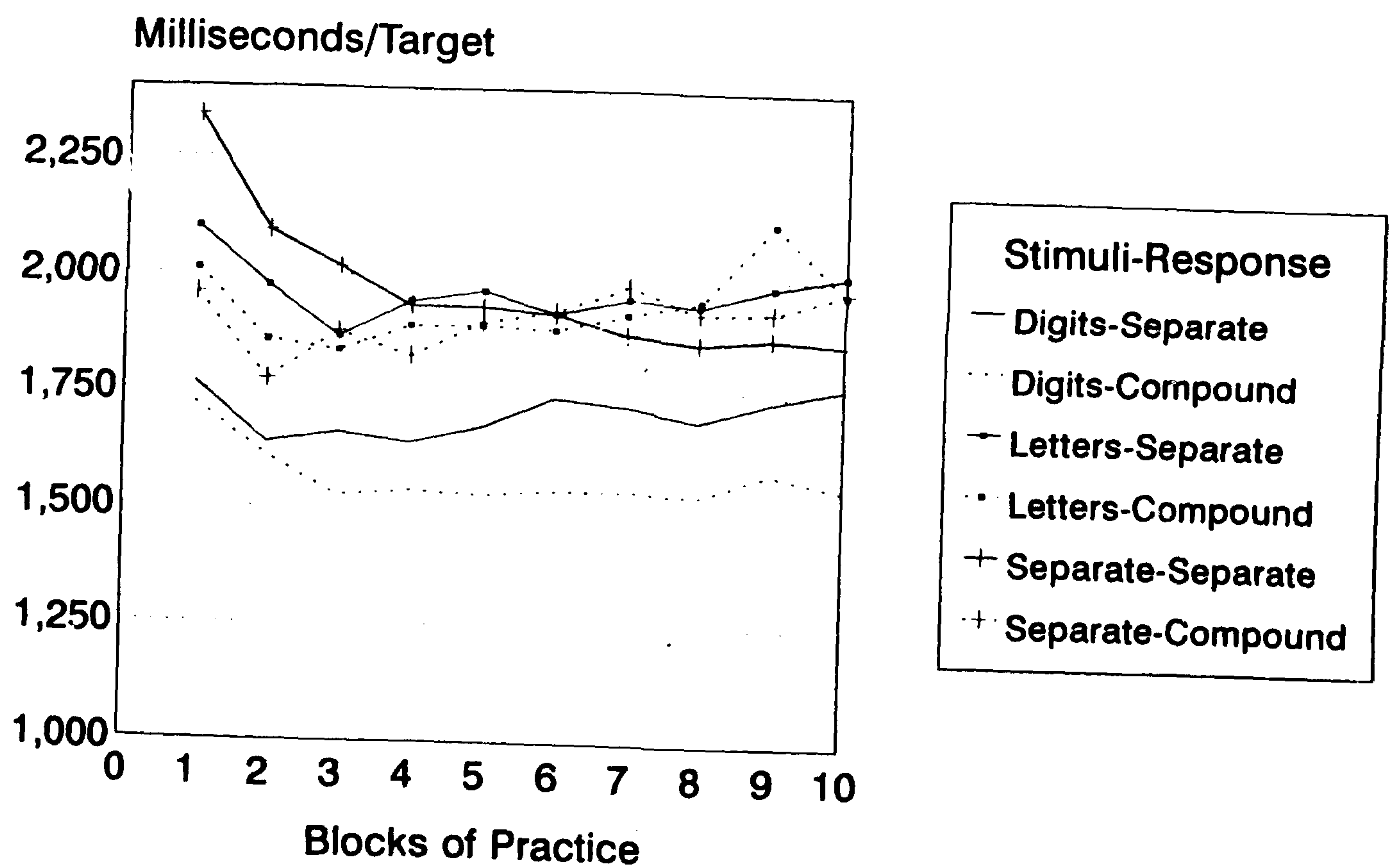


total time per target, the identification of digits was significantly faster than the identification of letters, or letters and digits (the separate condition). On average, digits took 1636 msec per target, letters required 1951 msec. per target and separate targets required 1940 msec. per target. Further, all three levels of number of targets to be identified were significantly different from one another. The greater the number of targets to be identified, the longer it took to input the information per target (1306, 1815, and 2405 msec. per target for the 2, 3 and 4 target conditions). As with the total time per target data, the block effect appears to reflect a significant drop in the input time per target early in practice, with a minimal drop later in practice. However, the Neuman-Keuls test for blocks showed that only block 1 (1982 msec. per target) was significantly different from the other blocks (1850 msec. per target on average for blocks 2-10). These findings are moderated by significant interaction effects.

There was a significant three-way interaction for the digits-letters-separate condition, response mapping and blocks. As illustrated in Figure 4-6, this effect was brought about by the condition where subjects identified digits and letters (separate targets) and used the separate response mapping condition which was significantly different from all other target-response conditions in the first block of practice. There were no other significant interaction effects in the input time per target data.

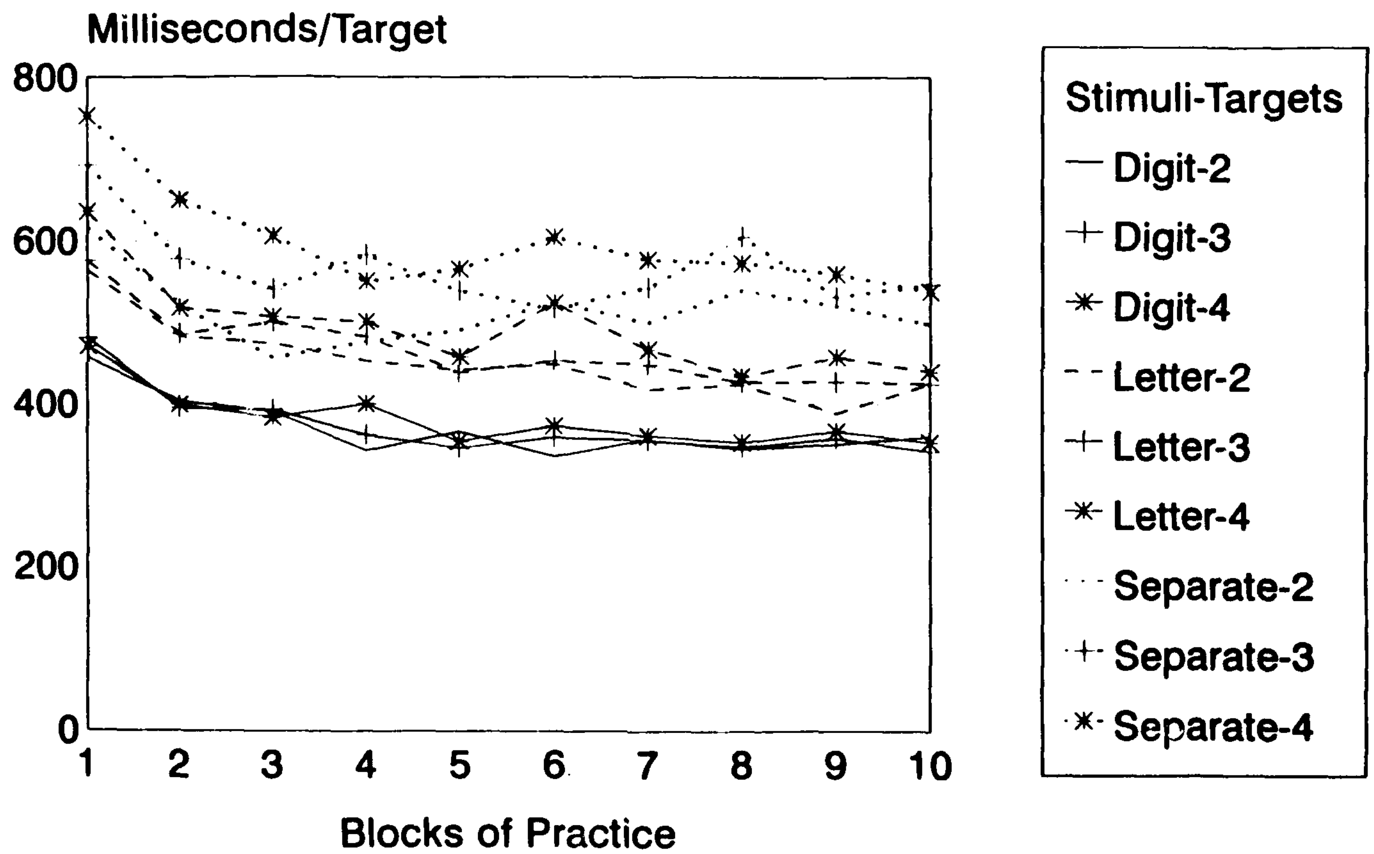
Output Time. Figure 4-7 reflects three significant output time main effects: the digit-letter-separate comparison ($\underline{F}=14.3$, $(2,53)$ $p < .01$), the target density effect ($\underline{F}=31.7$, $(2,106)$, $p < .01$), and the blocks effect ($\underline{F}=32.9$, $(9,477)$, $p < .01$). The output time per response was approximately 96 msec. per response faster for digits (375 msec. per response) than it was for letters (471 msec. per response), and the separate responses were 88 and 184 msec. per response slower than letters and digits respectively (559 msec. per response). The significant density effect reflects output times increasing significantly for all levels of the target density (446, 469 and 490 for the 2. 3 and 4 target

Figure 4-6. Digits, Letters, Separate: Input Time Condition by Response Mapping by Blocks Interaction



30 July 1992

Figure 4-7. Digits, Letters, Separate: Output Time



30 July 1992

conditions). As with total and input time, the block effect reflects a relatively large improvement early in practice, with minimal changes after block 4 (583 msec. per target for block 1, 461 msec. per target for block 4 and 436 msec. per target for block 10).

The results for output time, as shown in Figure 4-8 and Table 4-1, reflect one significant three-way interaction for the digits-letters-separate comparison, response mapping and target density ($\underline{F}=5.61, (4,106), p < .01$). The interaction reflects a significant difference between the condition where four, separate targets are identified using the compound response mapping. The changes in performance for the target-response mappings are described in more detail by the linear equations:

$$\text{Output Time}_{\text{Digits-Separate}} = 2.4\ (\text{Number of Targets}) + 381.5\ \text{Msec. per Target}$$

$$\text{Output Time}_{\text{Digits-Compound}} = 64.6\ (\text{Number of Targets}) + 205.9\ \text{Msec. per Target}$$

$$\text{Output Time}_{\text{Letters-Separate}} = 15.9\ (\text{Number of Targets}) + 420.7\ \text{Msec. per Target}$$

$$\text{Output Time}_{\text{Letters-Compound}} = 17.3\ (\text{Number of Targets}) + 423.6\ \text{Msec. per Target}$$

$$\text{Output Time}_{\text{Separate-Separate}} = 10.5\ (\text{Number of Targets}) + 513.9\ \text{Msec. per Target}$$

$$\text{Output Time}_{\text{Separate-Compound}} = 48.6\ (\text{Number of Targets}) + 470.2\ \text{Msec. per Target}$$

The slopes for the Separate-Compound and Digits-Compound regressions indicate a larger increase in output time for the identification of separate targets using a compound response mapping condition as the target density increases. The significant three-way interaction is due to the minimal slope found for the compound response mapping when identifying letter targets relative to the other compound response conditions.

There were several significant two-way interactions found in the output time per target data. The first was for the digits-letters-separate comparison and target density ($\underline{F}=6.91, (4,106), P < .01$). As suggested by the significant three-way interaction described above, this was due to the

Figure 4-8. Digits, Letters, Separate: Output Time Condition by Response Mapping by Number of Targets Interaction

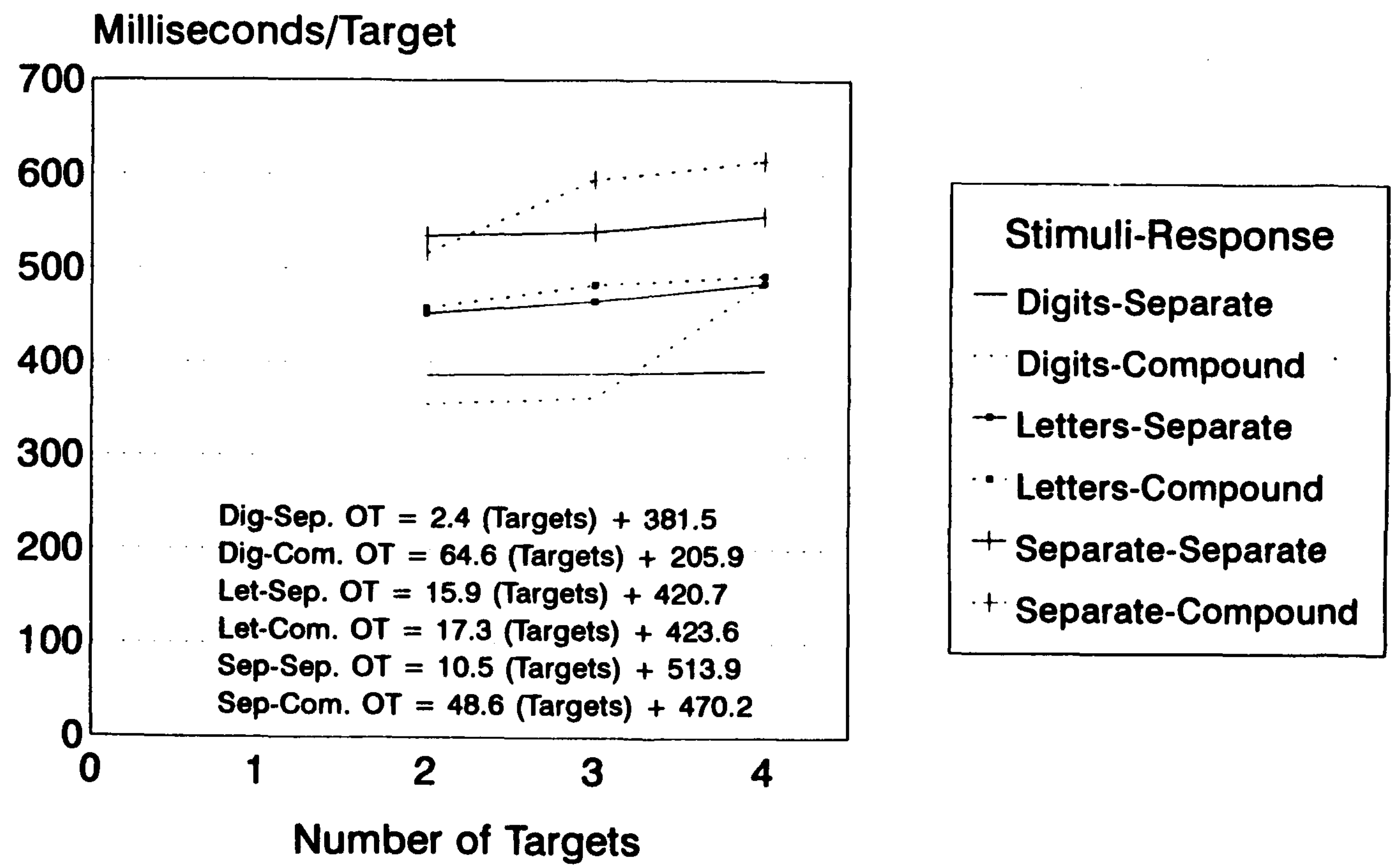
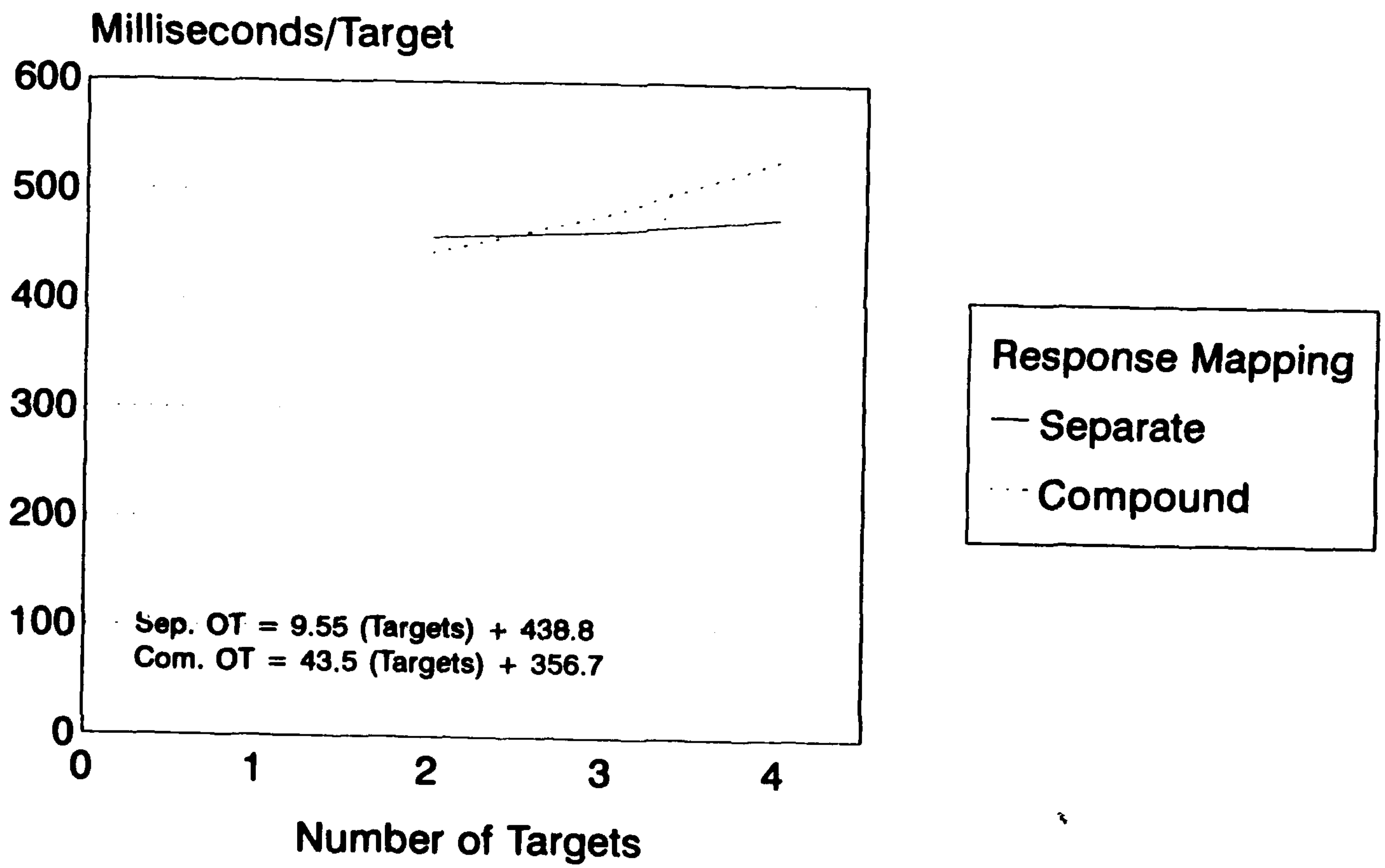


Figure 4-9. Digits, Letters, Separate: Output Time Response Mapping by Number of Targets Interaction



7 March 1992

identification of letter target codes using the compound response mapping condition not increasing with the target density, while the identification of digit codes with the compound response mapping and separate targets with the compound response mapping conditions did. The second significant two-way interaction in the output time data was for the response mapping and density manipulations. This interaction, illustrated in Figure 4-9, shows that the overall rate of identifying the compound targets increased approximately 4.5 times faster for using the compound response mapping (43.5 msec. per target^2) than it did for using the separate response mapping (9.55 msec. per target^2). The regressions for the functions shown in Figure 4-9 are:

$$\text{Output Time per Response}_{\text{Separate Panel}} = 9.55\ (\text{Targets}) + 438.8 \text{ msec. per target}$$

$$\text{Output Time per Response}_{\text{Compound Panel}} = 43.5\ (\text{Targets}) + 356.7 \text{ msec. per target.}$$

As with the digit-letter comparison, significant effects were found for the number of blocks of practice in all latency measures. The practice effects appear to reflect a typical learning curve wherein there is a significant improvement in performance from block to block in the first few blocks, and relatively little improvement in later blocks. Therefore, in order to assess performance changes early in practice independent of those where performance is relatively stable, two analyses are reported below. The first is for blocks 1-3 of practice and the second is for blocks 4-10 of practice. Tables 4-2 and 4-3 summarize the results of these analyses.

Blocks 1-3.

Percent Correct. There was one significant effect for the performance accuracy, as measured by percent correct, in the first three blocks, this was for the target density manipulation ($\underline{F}$=3.26, (2,106), $p < .05$). The effect reflects the four targets condition being significantly worse than two or

TABLE 4-2. Summary of MANOVA results for Digits-Letters-Separate: First three blocks. [33] [34] [35]

EFFECT:	% CORRECT:	TOTAL TIME:	INPUT TIME:	OUTPUT TIME:
Condition (C)	$F=0.61(2,53)$ $p = .548$	$F=11.7,(2,53)$ $p < .01$	$F=5.63,(2,53)$ $p < .01$	$F=9.51,(2,53)$ $p < .01$
Response (R)	$F=2.34,(1,53)$ $p = .132$	$F=0.42,(1,53)$ $p = .520$	$F=2.38,(1,53)$ $p = .129$	$F=0.05,(1,53)$ $p = .818$
C_R	$F=0.62,(2,53)$ $p = .543$	$F=0.02,(2,53)$ $p = .984$	$F=0.54,(2,53)$ $p = .587$	$F=0.43,(2,53)$ $p = .650$
Targets (T)	$F=2.86,(2,106)$ $p = .062$	$F=813,(2,106)$ $p < .01$	$F=308,(2,106)$ $p < .01$	$F=25.0,(2,106)$ $p < .01$
C_T	$F=1.12,(4,106)$ $p = .352$	$F=10.2,(4,106)$ $p < .01$	$F=0.94,(4,106)$ $p = .444$	$F=10.4,(4,106)$ $p < .01$
R_T	$F=0.70,(2,106)$ $p= .501$	$F=1.03,(2,106)$ $p = .362$	$F=0.15,(2,106)$ $p = .858$	$F=3.36,(2,106)$ $p < .05$
C_R_T	$F=1.17,(4,106)$ $p = .327$	$F=0.96,(4,106)$ $p = .431$	$F=0.45,(4,106)$ $p = .769$	$F=5.04,(4,106)$ $p < .01$
Block (B)	$F=3.26,(2,106)$ $p < .05$	$F=813,(2,106)$ $p < .01$	$F=20.8,(2,106)$ $p < .01$	$F=78.8,(2,106)$ $p < .01$
C_B	$F=0.06,(4,106)$ $p = .992$	$F=1.74,(4,106)$ $p = .146$	$F=0.57,(4,106)$ $p = .685$	$F=2.96,(4,106)$ $p < .05$

[33] Contrast (C) refers to the comparison of the target-task conditions used in this analysis. Response (R) refers to the response panel mapping effect. Targets (T) refers to the number of targets being identified. Block (B) refers to the number of blocks of practice. Interaction effects are denoted by the abbreviation for the effects separated by an underscore, e.g. C_R indicates the Contrast by Response mapping interaction.

[34] Analysis uses {Digits-Digits-Separate, Digits-Digits-Compound, Letters-Letters-Separate, Letters-Letters-Compound, Separate-Both-Separate, Separate-Both-Compound} as groups.

[35] Table based on revised analyses - March 7, 1992.

R_B	$F = 1.35, (2,106)$ $p = .265$	$F = 0.63, (2,106)$ $p = .532$	$F = 0.69, (2,106)$ $p = .503$	$F = 0.06, (2,106)$ $p = .943$
C_R_B	$F = 1.65, (4,106)$ $p = .168$	$F = 1.50, (4,106)$ $p = .207$	$F = 1.47, (4,106)$ $p = .216$	$F = 0.83, (4,106)$ $p = .509$
T_B	$F = 0.45, (4,212)$ $p = .771$	$F = 3.17, (4,212)$ $p < .05$	$F = 0.10, (4,212)$ $p = .981$	$F = 0.54, (4,212)$ $p = .710$
C_T_B	$F = 0.63, (8,212)$ $p = .754$	$F = 1.22, (8,212)$ $p = .288$	$F = 1.31, (8,212)$ $p = .237$	$F = 0.26, (8,212)$ $p = .976$
R_T_B	$F = 1.18, (4,212)$ $p = .318$	$F = 0.02, (4,212)$ $p = .999$	$F = 0.32, (4,212)$ $p = .867$	$F = 0.84, (4,212)$ $p = .835$
C_R_T_B	$F = 1.08, (8,212)$ $p = .377$	$F = 0.60, (8,212)$ $p = .774$	$F = 0.30, (8,212)$ $p = .966$	$F = 1.41, (8,212)$ $p = .193$

TABLE 4-3. Summary of MANOVA results for Digits-Letters-Separate: Blocks 4 through 10 of practice.[36] [37] [38]

EFFECT:	% CORRECT:	TOTAL TIME:	INPUT TIME:	OUTPUT TIME:
Condition (C)	$F=2.25,(2,53)$ $p = .116$	$F=11.5,(2,53)$ $p < .01$	$F=4.10,(2,53)$ $p < .05$	$F=16.1,(2,53)$ $p < .01$
Response (R)	$F=1.20,(1,53)$ $p = .278$	$F=0.01,(1,53)$ $p = .907$	$F=0.24,(1,53)$ $p = .624$	$F=0.01,(1,53)$ $p = .913$
C_R	$F=0.75,(2,53)$ $p = .479$	$F=0.57,(2,53)$ $p = .569$	$F=0.34,(2,53)$ $p = .711$	$F=0.32,(2,53)$ $p = .728$
Targets (T)	$F=10.2,(2,106)$ $p < .01$	$F=900,(2,106)$ $p < .01$	$F=431,(2,106)$ $p < .01$	$F=15.7,(2,106)$ $p < .01$
C_T	$F=0.16,(4,106)$ $p = .959$	$F=8.12,(4,106)$ $p < .01$	$F=2.45,(4,106)$ $p = .050$	$F=2.29,(4,106)$ $p = .064$
R_T	$F=1.60,(2,106)$ $p= .206$	$F=0.90,(2,106)$ $p = .408$	$F=0.44,(2,106)$ $p = .644$	$F=13.2,(2,106)$ $p < .01$
C_R_T	$F=0.55,(4,106)$ $p = .701$	$F=0.84,(4,106)$ $p = .503$	$F=0.07,(4,106)$ $p = .990$	$F=2.96,(4,106)$ $p < .05$
Block (B)	$F=0.35,(6,318)$ $p = .910$	$F=0.72,(6,318)$ $p = .635$	$F=2.06,(6,318)$ $p = .058$	$F=1.79,(6,318)$ $p = .099$
C_B	$F=0.86,(12,318)$ $p = .590$	$F=0.96,(12,318)$ $p = .489$	$F=0.86,(12,318)$ $p = .586$	$F=1.72,(12,318)$ $p = .062$

[36] Contrast (C) refers to the comparison of the target-task conditions used in this analysis. Response (R) refers to the response panel mapping effect. Targets (T) refers to the number of targets being identified. Block (B) refers to the number of blocks of practice. Interaction effects are denoted by the abbreviation for the effects separated by an underscore, e.g. C_R indicates the Contrast by Response mapping interaction.

[37] Analysis uses {Digits-Digits-Separate, Digits-Digits-Compound, Letters-Letters-Separate, Letters-Letters-Compound, Separate-Both-Separate, Separate-Both-Compound} as groups.

[38] Table based on revised analyses - March 7, 1992.

R_B	F=1.27,(6,318) p = .271	F=1.65,(6,318) p = .132	F=1.00,(6,318) p = .422	F=1.89,(6,318) p = .082
C_R_B	F=0.38,(12,318) p = .969	F=0.78,(12,318) p = .676	F=1.13,(12,318) p = .322	F=0.95,(12,318) p = .500
T_B	F=1.15,(12,636) p = .318	F=1.19,(12,636) p = .287	F=0.89,(12,636) p = .554	F=1.59,(12,636) p = .090
C_T_B	F=1.10,(24,636) p = .332	F=1.13,(24,636) p = .303	F=1.18,(24,636) p = .251	F=0.78,(24,636) p = .763
R_T_B	F=0.91,(12,636) p = .537	F=0.84,(12,636) p = .604	F=0.67,(12,636) p = .783	F=1.06,(12,636) p = .392
C_R_T_B	F=1.46,(24,636) p = .074	F=0.99,(24,636) p = .476	F=1.02,(24,636) p = .443	F=0.55,(24,636) p = .960

three targets conditions (97.4, 97.3 and 95.2 percent correct for the 2, 3 and 4 target conditions).

Total Time. The analysis of total time per target data for blocks 1-3 revealed three significant main effects. The first was for the digit-letter-separate comparison (F=11.7, (2,53), $p < .01$). This effect was due to the separate condition (3857 msec. per target) taking significantly longer than the digits (2912 msec. per target) or letters (3541 msec. per target) conditions. The second main effect was for target density, (F=308, (2,106), $p < .01$) where all density conditions were significantly different from each other (2 = 2315 msec. per target, 3 = 3379 msec. per target, 4 = 4615 msec. per target). The third significant main effect was for number of blocks (F=20.8, (2,106), $p < .01$). The block effect reflects a significant improvement through the first three blocks.

The total time data for the first three blocks also revealed a significant density by block interaction (F=3.17, (4,212), $p < .05$). This effect reflects a greater improvement for conditions with more targets to be identified over the first three blocks of practice, (seen in Figure 4-3). A second interaction effect was found for the digits-letters-separate comparison and target density (F=10.2 (4,106), $p < .01$). This interaction reflects the difference between the separate condition and the other conditions increasing as the density increased.

Input Time. The input time per target data for blocks 1-3 showed the same significant main effects as did the total time per target data for the same period. Effects were found for the digit-letter-separate comparison (F=5.63, 2,53), $p < .01$), the target density (F=308, (2,106), $p < .01$), and blocks (F=20.8, (2,106), $p < .01$). The digits-letters-separate comparison effect was due to the digits condition (1653 msec. per target) being significantly faster than the letters or separate conditions (1941 msec. per target, 2009 msec. per target). The targets effect was due to an increase in the time required per target as the target density increased (1343, 1831, and 2429 msec. per target for the 2, 3

and 4 targets conditions). The block effect represents a significant improvement in performance over the first three blocks (1982, 1824 and 1798 msec. per target for blocks 1, 2 and 3).

Output Time. The significant effects with output time over blocks 1-3 were the same as those seen in output time for all blocks of practice. Again there were three significant main effects: the digits-letters-separate comparison (F=9.51, (2,53), $p < .01$), target density (F=25.0, (2,106), $p < .01$) and blocks (F=78.8, (2,106), $p < .01$). The direction of these effects was the same as for total and input time, however the magnitude was much smaller. The digits-letters-separate comparison effect showed that the digits condition was responded to faster than the letters or separate conditions (419, 527 and 600 msec. per target for the digits, letters and separate conditions). The rate of responding decreased as more targets were to be identified, (485, 515 and 546 msec. per target for the 2, 3 and 4 targets conditions). The blocks effect demonstrated an improvement in performance across blocks 1-3 (583, 492, 471 msec. per target for blocks 1,2 and 3).

As expected based on the results described for output time over all blocks, there was a significant three-way interaction in the data over blocks 1-3 for the digits-letters-separate comparison, response mapping, and target density (F=5.04, (4,106), $p < .01$). This effect was due to the separate-compound response mapping condition being significantly slower when four targets were identified, relative to other conditions. There was a significant digits-letters-separate comparison by density interaction (F=10.4, (4,106), $p < .01$) consistent with the results of the overall analysis, i.e. responding to the digits and separate target conditions slowed as the target density increased substantially, while that for the letters targets slowed very little. There was also a significant response mapping by number of targets interaction (F=3.36, (2,106), $p < .05$) due to a decrease in the rate of responding with the compound response mapping as the number of targets increased, while the rate of responding was more stable for the separate response mapping conditions.

Blocks 4-10.

Percent Correct. Only one significant effect was found in the percent correct data for blocks 4-10, and this was for the target density, ($F = 10.2$, (2,106), $p < .01$). As with the overall analysis, this effect was due to the digits condition being significantly more accurate than the letters or separate conditions (97.7%, 96.9% and 95.2% respectively).

Total Time. The analysis of the total time per target data for blocks 4-10 of practice revealed no significant effects involving blocks, supporting the interpretation that learning is essentially complete by block 4. There were significant main effects for the digits-letters-separate comparison, ($F = 11.5$, (2,53) $p < .01$), where the separate condition (3354 msec. per target) was significantly slower than the digits (2704 msec. per target) or letters (3309 msec. per target) conditions. There was still a significant density effect ($F = 900$, (2,106), $P < .01$). As with the overall analysis, and that for blocks 1-3, all levels of density were significantly different from each other (2150, 3156 and 4262 for the 2, 3 and 4 targets conditions).

Input Time. The significant main effects for input time per target for blocks 4-10 included the digits-letters-separate comparison ($F = 4.10$, (2,53), $p < .05$), and number of targets identified ($F = 431$, (4,106), $p < .01$). The comparison effect was due to the digits condition being significantly faster than the letters and separate conditions (1628 msec per target versus 1955 and 1910 msec. per target respectively). The density effect was due to an increase in the time required to input targets as the number of targets in the display increased (1290, 1808 and 2395 msec. per target for the 2, 3 and 4 target conditions). There were no significant interaction effects for input time in blocks 4-10.

Output Time. The output time per target data for blocks 4-10 showed three significant main effects. First, as with the overall and early blocks of practice analyses, there was a main effect for the digit-

letter-separate comparison ($\underline{F}$=16.1, (2,53), $p < .01$). This was due to the output time per target for the digits, letters and separate target conditions being different from each other (357, 447 and 542 for digits, letters and separate). There was a main effect for target density, ($\underline{F}$=15.7 (2,106), $p < .01$) where the rate of responding decreased as the density increased (447, 450 and 467 for the 2, 3 and 4 target conditions). The significant three-way interaction for the digits-letters-separate comparison effect, response mapping and number of targets found in the overall analysis and blocks 1-3 remained as well ($\underline{F}$=2.96, (4,106), $p < .05$). Again this was due to a significant difference for the separate targets responded to using the compound response panel when four targets were identified. The two-way interaction found in the other total time analyses for response mapping and target density remained significant as well ($\underline{F}$=13.2, (2,106), $p < .01$).

DISCUSSION

The analyses for the digits-letters-separate comparison show that there are indeed significant performance differences between identifying digits or letters versus identifying digits and letters (separate) targets. The effects occur both when the task is novel and after extensive practice. Therefore, in accordance with hypothesis 1, it may be concluded that there are significant differences between the identification of single element alphanumeric codes from single and multiple categories. The specific findings with regard to the digits, letters and separate comparison, the response mapping, target density, and blocks for each of the dependent measures, will be discussed in detail below. However, before the specific findings are assessed, a potential caveat with regard to this data is in order due to the nature of the results with the percent correct data.

The assessment of performance accuracy in this study requires some caution. The percent correct data is very close to 100%, which corresponds to the maximum limit of the scale. It could therefore be argued that the significant effects found in the percent correct data, as well as the other performance indices, is being affected by an accuracy ceiling effect. This means that the sensitivity of the percent correct data in assessing accuracy may be disproportionately enhanced or suppressed due to the nature of the percent correct scale, and therefore the effects seen may not truly be representative of actual performance. Further, due to the tendency for an interrelationship between speed of responding, as indicated by the latency measures, and accuracy, measured by the percent correct data, the latency measures may be affected as well (Pachella, 1974; Pachella & Pew, 1968). However, the magnitudes and consistency of the findings across conditions suggests that a ceiling effect has not seriously impacted this study, and the results will be interpreted below without further mention of this issue. Table 4-4 summarizes the actual and relative changes in each of the

Table 4-4. Digits, Letters, Separate:
Differences for Significant Latency Main Effects.

Significant Effect	Total Time Actual Change	Total Time % Change	Input Time Actual Change	Input Time % Change	Output Time Actual Change	Output Time % Change
Comparison:						
Digits-Letters	612	22.1%	315	19.3%	96	25.6%
Digits-Separate	878	31.7%	304	18.6%	184	49.1%
Letters-Separate	266	7.9%	-11	-1.0%	88	18.7%
Targets: 2-4	2168	98.5%	1099	84.2%	44	9.9%
Blocks: 1-10	-579	-15.5%	-125	-6.7%	-146	-33.4%

Actual Time in Milliseconds. Group means used to generate this Table may be found in Appendix B.
% Change = Actual Change / (Larger of the Mean Times for that comparison) * 100.
30 July 1992

significant latency main effects, and will serve as the basis for much of the remaining discussion.

Experimental Manipulations

Target-Task. The results with regard to the identification of single code targets from single code categories shows that there are clear and persistent differences in the time required to identify targets from each of the code categories. All latency measures showed significant main effects for the digits-letters-separate comparison, though there were no significant differences with regard to accuracy. Specifically, digits were identified approximately 22% faster overall, 19% faster in terms of input time per target, and 26% faster in terms output time per target.

The identification of targets from single code categories versus multiple code categories generated mixed results. The overall latency in identifying digits and letters is significantly longer than digits, but not significantly different from letters. When total response latency is partitioned into input and output time, some interesting aspects of the differences are revealed. With regard to input time, the letter targets were input 19% (315 msec. per target) slower than digit targets, and letters were taken from memory and translated to a response 26% (96 msec. per target) slower on average than digit targets. Comparing the identification of digits and letters to letters only or digits only reveals that the separate codes were read from the display and encoded into memory 19% (304 msec. per target) slower than letters, and were taken from memory and translated to a response 49% slower than identifying digits alone. The input and output times for identifying digits and letters are even more intriguing because the input time for identifying digits and letters was actually 1% (11 msec. per target) faster than identifying only letters, and output time per target increased 19% (88 msec. per target). Therefore, it appears that identifying symbols from multiple categories will lead to an identification rate comparable to that seen in the slowest of the individual categories,

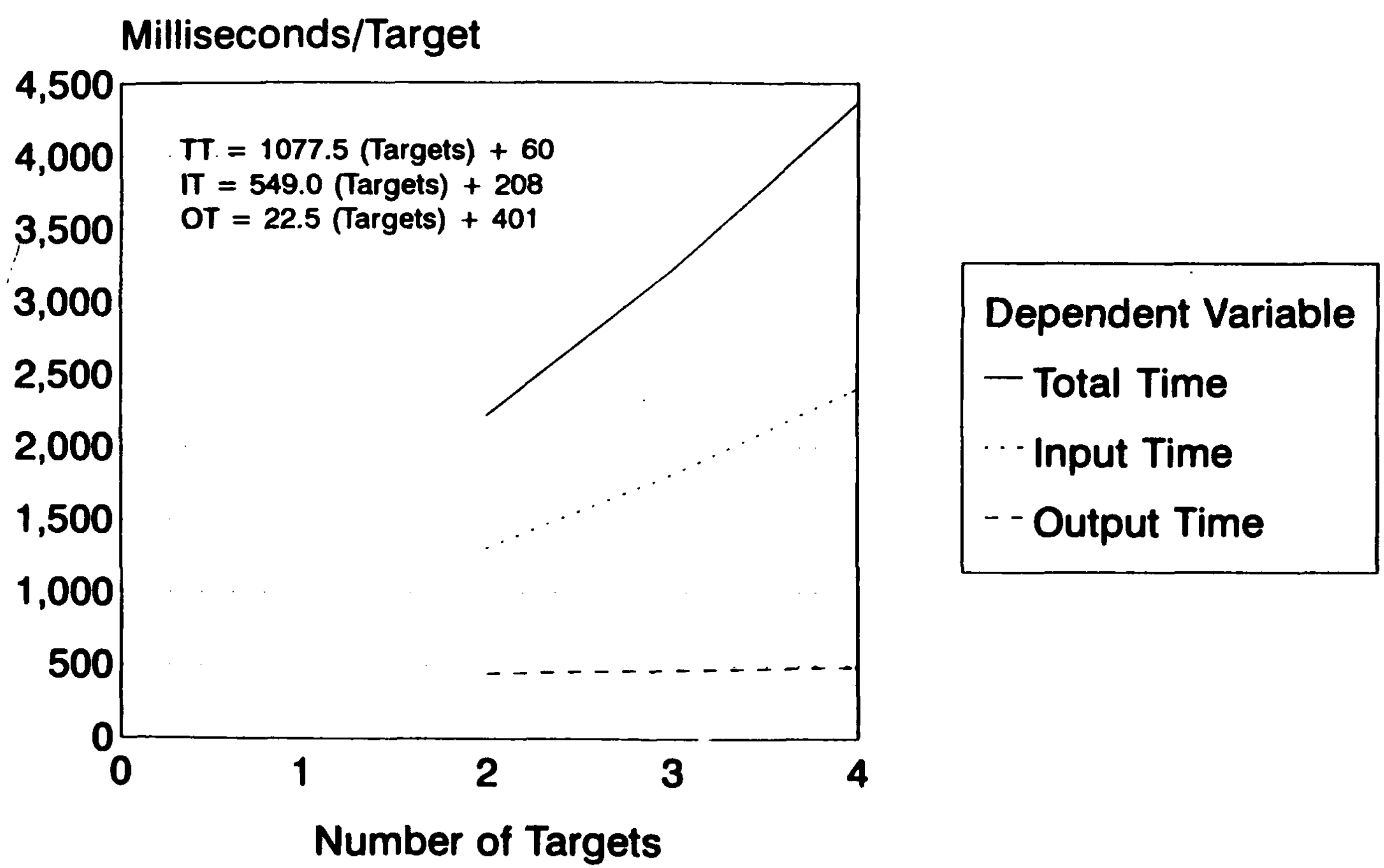
while the output rate will be the cumulative sum of times required for each of the component code categories.

These results support Teichner's (1977) arguments distinguishing between input and output processing. In effect, the majority of the processing (i.e. translation, denoted by Teichner, 1977; Teichner & Williams, 1977 as one or more occurrences of T_{S-S}) occurs during input. The rate of input is, in part, a function of the particular code used. Codes that lend themselves to more efficient encoding, e.g. digits, are encoded into memory and processed more rapidly. As shown in Figure 4-10, the encoding of information into memory requires approximately three times as much time as does the translation of the target from memory to a response. Some code dependent processing does take place in output however, as evidenced by the significant output time effects for the digits, letters and separate conditions. The data indicates that the introduction of additional code categories to the identification task will cause input processing to be only as good as that seen with the least efficiently processed of the component code categories. Looking at the actual change in output time, however, suggests that the introduction of additional code categories to the identification task will cause output processing to increase to a rate equivalent to the sum of the rate for each of the component codes.[11]

The finding that digits are input faster than letters and the finding that input are as slow as that for the slowest of the code categories present in a display suggests that Briggs may be correct in his suggestions regarding the nature of code categories. These results could be accounted for by the fact that digit category has fewer elements than does the letter category. However, if this explanation is pushed to its conclusion, one would expect that the separate codes would be identified

[11]This hypothesis could be tested by generating an empirical or theoretical estimate for mean movement time in making the responses with this particular apparatus (e.g. Fitts, 1954), and subtracting that time from the output time per response. Such an effort is beyond the scope of this study, however.

Figure 4-10. Digits, Letters, Separate:
Total, Input & Output Time by Number of Targets.



7 March 1992

even more slowly than are each of the component (digit or letter) categories. A logical approach to testing this hypothesis would be to use novel code symbols and manipulate the experience (knowledge) regarding the associations among those elements, i.e. their association in a category. If a larger categories are input more slowly than smaller categories, then Briggs' hypothesis would be confirmed.

The finding with regard to output processing seems entirely consistent with Briggs' hypothesis in that the identification of digits and letters was slower than that for digits or letters. However, the responses in this experiment with two code categories clearly required the consideration of a larger number of keys. Therefore, this result should not be interpreted as supporting Briggs' explanation for the difference between the digit and letter categories. Again, a more careful consideration of the number of responses, by limiting the number of response alternatives should allow the effects of the number of codes in the response set and its effect on output to be considered relative to the size of the code categories.

Target density. The examination of the performance changes seen with the target density sheds further light on the nature of input and output processing. The accuracy data showed that accuracy decreased with an increase in density, though the actual change seen in this study was small, and may not be very meaningful. Further, accuracy did not change in any way as a function of the types of codes being identified. The latency data, however, showed that the time required to identify targets increased in terms of input, output and overall response times with increases in density. Table 4-4 shows that doubling the number of targets doubled the total time per target required to identify targets (an actual change of 2168 msec. per target). The input time and output time, however, showed very different net change results for the target density. Input time nearly doubled (84% or 1099 msec. per target) with the doubling of target density, while output time increased a mere 10% (44 msec. per target).

The results with the target density manipulation supports the suggestion that output time does represent a limited amount of symbolic processing (e.g. translation) because there are significant changes in the output time per target with changes in the density of target symbols being identified. If codes were not being processed in output, then there would be no reason for the rate of output to change with number of responses that are required. However, because the amount of change is very small relative to that seen due to type of codes being identified, it is reasonable to assert that the code translations that go on in output are of a different character than those seen in input. Input processing is highly influenced by both the number and type of targets being identified. This supports the assertion that the strategy adopted while encoding targets from the display is the most important factor in affecting the input time. The presence of additional targets in the display effectively magnifies the differences seen due to encoding strategy, as supported by Figure 4-4 and the regressions seen for total time per target as a function of the target density for digits, letters and the separate targets.

The regressions seen in Figure 4-8 show that the magnitude of change for output time with increases in the target density is much smaller than those seen in input or total time. Again, this can be explained by the assumption that the proportion of output time accounted for by processing is substantially less than that for input time due to the inclusion of movement time as part of the output time measure. The effects of output time are also moderated by the significant digits-letters-separate by response mapping by density interaction, suggesting that all these factor are having an impact on the processing that takes place in output.

Response Panel Mapping. The impact of the response mapping on identification is complex and subtle. In fact, all response mapping effects are seen only in the form of interactions with other factors manipulated in this study. Further, the effects seen for the response mapping were seen primarily in output time, as would be intuitively expected given Teichner's definition of output

processing. In accordance with hypothesis 7, it may be concluded that response mapping does affect output processing. However, there was one input time interaction involving the response mapping manipulation, supporting hypothesis 6. The results for the digits-letters-separate comparison by response mapping by blocks interaction illustrated in Figure 4-6, show that there that the output side of the task can affect the way information is taken from a display and encoded into memory for certain information codes, early in practice. It can therefore be speculated that the impacts of the output side of the task on the input side of the task are transitory. Stated as a design principle, this result might state that: the output (response) side of the task will impact the reading of a display, and the encoding of that information into memory when the task is novel and/or performed infrequently and the codes used are from relatively large coding sets and/or are complex (from multiple categories).

The significant digits-letters-separate comparison, response mapping by target density interaction for output time supports the assertion that the output processing is sensitive to the particular code being identified. In effect, the use of compound response mappings causes a significant decrease in the rate of processing as the target density increases. However, it is apparent from Figure 4-8 there are three distinct patterns of changes for the output time data as a function of this interaction. The identification of targets in multiple code categories (the separate condition) causes a linear increase in output time per target of about 20% when targets are identified using the compound response mapping. The identification of the letter targets also generated a linear function for the target density. However, the rate of increase was minimal (about 16.5 msec. per target[2]). Further, there was no difference between the slopes for the letter conditions as a function of response mapping. As with the separate targets, the digit targets generated two distinct functions for the target density depending on the response mapping. The separate response mapping, when used to identify digits, generated a function essentially similar to that seen for separate and letters conditions when identified with the separate response panel functions, and in identifying the letter

targets with the compound mapping. However, the digit targets identified with the compound response mapping generated a curvilinear function as the target density was increased. In effect, the function resembled that for the separate response mappings and the letters with the compound response mapping when few targets (up to three) were being identified, and resembled the separate targets-compound response mapping condition when more than three targets were identified. Keeping in mind that there were only three levels of target density, it is speculated that the output processing of digits is essentially similar to that seen with compound targets and the compound response mapping. Further, the added complexity of the compound response mapping, as measured by the rate of increase in time required per target for increasing number of targets, (the slopes of the regressions seen in Figure 4-8), suggests that the costs associated with the compound response mapping increase with the number of responses required, particularly for certain categories of codes. It is not clear, however, why the separate, and particularly the digits, target conditions should involve more difficult translations from memory to responses. One possible explanation relates to the issue of response interference. It may be speculated that the subject population used (undergraduates at an engineering school) were extensively familiar with the standard computer keyboard, and particularly the standard numeric keypad layout on those keyboards. The assignment of digits to the response mappings used in this task did not match the standard numeric keypad layout, and therefore may have required additional processing in order to counter the intuitively expected relationships among the digit keys. Based on this explanation, it is further speculated that increasing the number of responses required would generate significant main effects for the response panel manipulation, with the compound response mapping generating longer output times per target.

Blocks of Practice. Amount of experience with the specific identification task clearly has an effect on performance as measured by both percent correct and response latency. The results from the overall analyses, as well as those from early in practice (blocks 1-3) and late in practice (blocks 4-10) show that there were significant and meaningful improvements in performance in terms of increased

accuracy and increased rate of responding with practice. Overall, Table 4-4 shows that there was a 16% (579 msec. per target) improvement in the rate of target identification through the course of the experiment. Further, the failure to find significant practice effects in the analyses for blocks 4-10 support the assertion that learning is essentially completed for these identification tasks after 30 trials. Thus, the learning effects are rapid.

The latency data demonstrated a number of interaction effects between blocks and the other experiment manipulations, generally involving the number of codes being identified as well. Thus, there was a greater improvement in performance when there was a higher symbol density, and there was more complex coding in terms of both the number of potential target codes, and the complexity of the response mapping. The partitioning of total time revealed a number of subtle aspects as to how practice affects processing in an identification task. Despite output time accounting for only 20% of total time, approximately 50% of the total improvement in the rate of identification is accounted for by output time (125 msec. per target improvement in input, and 146 msec. per target improvement in output). As a result, there is a 33% increase in the rate of responding in output time and only a 7% improvement in input time. Therefore, practice is clearly most beneficial in the execution of responses and/or the translation of targets to response codes. Given the similar order of magnitude for the changes seen for the digits-letters-separate manipulation, and blocks, and the smaller changes seen for number of targets, it is speculated that the large changes in performance due to practice seen in output time reflect more the changes in output processing, (e.g. in reducing the response interference effects speculated about above), rather than the learning of mechanical responses. This is based on the assumption that if a greater percentage of the learning were in learning to move around the response panel, the order of magnitude of changes seen in output time for identifying the separate targets would be comparable to those seen in the other experimental manipulations. Further, the factors selected for manipulation in this study were selected because of their theoretical relationship to information processing. Numerous counter-balancing steps were

taken to minimize the impact of response movements across subjects (see Chapter 3 for details on the counter-balancing procedures). Therefore, it is concluded that the significant interactions seen in output time per target among the experiment manipulations, are due to the information processing associated with output time, rather than the mechanical aspects of response execution per se.

Summary of Results

The results for each of the experimental predictions is summarized below:

1. There were significant differences in performance between the digits targets and letters targets as measured by total, input and output time. Therefore, the processing of digits in an identification task is different from the processing of letters, and it may be asserted that digits and letters represent different sub-categories of alphanumeric codes. The results of this study show that digits are identified faster than letters.

2. The identification of a composite category (e.g. the *separate* task condition of digits and letters) generated some interesting results. In terms of overall performance as measured by total time, the identification of targets from multiple code categories generated performance comparable to the performance of the worst of the component codes, i.e. the rate of identification for separate targets was equivalent to the rate of identification of letters and slower than that for digits, although there was an actual increase of 266 msec. in identifying digits and letters over identifying letters alone. This would lead to the conclusion that this data did not generate support for the hypothesis that the identification of codes from a composite category was different from that of single categories.

   The partitioned latency data suggests a different conclusion. The pattern of significant differences for input time was the same as that seen for total time, i.e. the input of digits was faster than the input of letters, or, letters and digits. However, the output time data showed performance differences for the identification of targets from the composite code

category, and the separate targets were output more slowly than digits. Thus, the partitioning of response time into input and output components suggests that the costs for identifying a composite code category are incurred in making responses, rather than in reading the codes from the display and encoding them into memory. Digits and letters are processed as distinct code categories during output.

Hypothesis 2a related to the magnitude of change seen from the comparison of target sets representing single versus multiple code categories. It was stated that: if the composite code set has performance that at least twice as bad, i.e. less accurate and slower, than that seen in either of the component categories, then the change in performance is due to the processing of additional codes in a larger code set. Clearly this hypothesis is not supported, because the results found did not show that the separate targets required more time to identify than both of the component, single, code categories.

The results do support hypothesis 2b. The performance seen with the composite code category (the separate targets) was generally comparable to that seen in the worst of the single codes (letters). Therefore, the changes in performance due to the nature of the codes being identified in this task must be due to differences in the strategies involved in the processing of the codes being used. If it is assumed that processing takes place at a constant rate for all code categories, then the only way one category of codes could be input more quickly than another is if the faster codes are encoded more efficiently. Teichner (1977) would suggest this processing efficiency is due to the faster code category requiring fewer translations ($T_{S\text{-}S}$).

3. The response mapping demonstrated significant performance effects as measured by all three latency measures. Therefore, the response mapping does affect processing in an

identification task. The effects, however, were only seen in the form of interactions with other experiment manipulations, and the bulk of the effects were associated with output processing.

4. Significant effects were found for blocks with performance improving as the amount of practice increased. As predicted, the bulk of the learning took place early in practice, as confirmed through the separate analyses for blocks 1-3 and 4-10. However, the performance differences were found strictly in the latency measures. The accuracy of task performance did not change as a function of practice.

5. The presence of a significant three-way interaction for the digits-letters-separate comparison, response mapping and blocks for the input time per target data provides empirical support for hypothesis 6. Thus, it may be concluded that the response mapping affects the way people read a display and encode information into memory. However, the effect appears to be subtle, being dependent on the specific type of codes being identified, and short lived, disappearing with practice. The effect could be explained by suggesting that the first part of output in this task includes a secondary input, wherein additional information relating to the response mapping is input into memory at the start of output. The information input is speculated to involve information regarding the particular position of the desired response keys and facilitating the construction of a response mapping (T_{S-R}) in Teichner's model. (See Chapter 8 for an in depth discussion of this issue.)

6. The response mapping clearly affects the way information is taken from memory and translated to a response, as stated by hypothesis 7. However, this hypothesis is supported by a variety of significant two-way interaction effects between various experiment manipulations for the output time per target data, rather than a significant main effect for response

mapping per se. There were interaction effects between response mapping and the type of codes being identified, and the target density. Again, because one of the interactions involved the target density, and the output time measure was adjusted for the number of targets identified, it is concluded that the response mapping is having an effect on the rate of output processing.

Objectives

There were a number of theoretical, methodological and application objectives to be addressed by this study. These objectives have been met, and will now be discussed in turn. The first objective was quite general, making it the most difficult objective to talk about, i.e. demonstrating the utility of the WiTS methodology in assessing performance in an identification task. With slight modifications to the standard WiTS methodology, it has been possible to demonstrate that there are differences in performance in a target identification task. This study successfully manipulated aspects of the task, including the particular subsets of codes used, the response mapping, the target density, and amount of experience subjects had with the task, to demonstrate the changes in performance associated with these factors. Therefore, objective 1 has been met. Further, the primary methodological modification consisted of converting the total and input time measures into time per target, or rate measures. Through this modification, it has been possible to interpret the various significant findings in terms of their effects on overall, input and output processing. Because this modification compensates for the additional time required to process additional targets, any main or interaction effects involving target density can be attributed directly to changes in the rate of processing. The processing which may have generated these results could be, and has been, speculated about.

The second objective was to specifically assess the relative performance of alternative display codes, alternative response mappings and their interaction with task demands such as the number of targets to be identified. Through use of the time per target measures, and the manipulation of target density, it was possible to describe the effects of these manipulations in terms of input and output processing. With regard to objectives 2 and 3, many of the results obtained by partitioning response time into input and output time were not intuitively expected, or obvious. This was particularly true in the assessment of the response mapping manipulation, for which there was no main effect, but which interacted with other experimental manipulations to generate different effects in input and output time.

Objective three was met by demonstrating: 1) Two comparable sets of abstract codes (consisting of the same number of digit targets or letter targets) generated different performance as measured by total, input and output time, and 2) that the identification of a composite set of codes (consisting of digit and letter targets) generated performance comparable to the worst performance seen from each of the component sets in input, and worse performance than either of the two component codes in output.

The impact of the response mapping generated a number of important findings from both theoretical and application standpoints, thus addressing objective 4. The response mappings used in an identification task can and do affect the way information is read in from a display and encoded into memory. No doubt, had the task been more complex and cognitively demanding, e.g. an information reduction or creation task, more profound effects could have been generated by the output side of the task on the input side of the task. The output side of the task was affected by the response mapping as well. However, the effect was subtle in that it appeared only in the form of interaction effects. Again, the use of more complex response mappings, and/or the use of a more demanding task would likely change the nature and magnitude of the response panel effects. These

results are important because they show that the extrapolation of empirical results from one research paradigm to another, or even different apparatus with the same paradigm will have to be done with caution. It is clearly not valid to simply assume that the use of different response demands will not affect the cognitive demands of task performance. In fact, it may be speculated that the extrapolation of results from well controlled and therefore artificially constrained tasks of empirical research will be highly compromised when applied to the much more complex real-world application.

Objective 5 addresses the degree to which a target identification task can be considered an information processing task. The finding of significant main and interaction effects for the target density for accuracy, total time per target, input time per target and output time per target clearly show that even this simple identification task has significant information processing components. Further, the significant results for input and output time show that both input and output contain significant processing aspects. Figure 4-10 illustrates the magnitude of the target density over all other experiment manipulations for total, input and output time per target. Figure 4-11 shows the relative contribution of input and output time per target to the total time per target. Together, these figures show that the rate of target identification decreases in a linear fashion as the number of targets increases. The majority of time is associated with input processing. However, output processing also slows down significantly. Further, the extrapolated intercept for input, output, and total times in Figure 4-10 are comparable to those typical form simple reaction time, i.e. when no decisions are required (e.g. Luce, 1986). Thus, in accord with the work of Briggs and his students (Briggs, Thomason & Hagman, 1978; Briggs, Peters & Fisher, 1972; Briggs & Swanson, 1970; Briggs & Blaha, 1969), it may be seen that when no targets are present in the display, the intercept for total time per target is 0, as one would intuitively expect. The y-axis intercept for the input time per target and output time per target regressions would be approximately 200 msec., corresponding to simple reaction time, or the typical mechanical response time when no choices are present. These findings support the interpretations of input and output time as suggested by Teichner's model for

the WiTS methodology, and support the assertion that input time and output time per target are predominantly indices of processing.

Objective six will be addressed in some detail in Chapter 5, where the impact of irrelevant codes in the display will be assessed, and where the results of this study will serve as the basis for the formulation of more specific hypotheses in the next chapter. In general, however, the results of this study will allow directional hypotheses to be formed with regard to the effects of practice on latency, the impact of response mappings on input and output latencies, the increase in total, and the effects of input and output latency per target as the target density increases.

Applications & Lessons Learned

One goal in this research was to provide results that would be meaningful to engineering, as well as theoretical applications. Therefore, this study will be summarized in the form of identifying prospective principles and guidelines in terms of both general methodological issues, and specific recommendations with regard to the use of digits, letters, and, digits and letters when they are both relevant to performing a task.

1. Digits are read from the display and encoded into memory faster than are letters on a per code basis.

2. Tasks in which both digits and letters are relevant, are read from a display and encoded into memory at a rate that is comparable to the reading in and encoding of letters only.

3. The data suggests that the input of information from a display will be performed at a rate comparable to the *slowest* of the rates for the individual codes on the display.

4. Digits are output from memory and responded to at a rate that is slower than that seen for letters, or digits and letters, particularly as a larger number of responses are required.

5. Tasks for which both digits and letters are responded to appear to be output at a rate that is nearly the sum of the outputs for each of the individual codes.

6. The data suggests that the output of information will be made at a rate that is approximately equal to the sum of the individual rates for each of the individual categories of codes that are being responded to.

7. The response mapping does have an effect on input processing, specifically early in practice when the task is novel and the performer is unfamiliar with it. In this experiment, the use of a single code per response mapping caused input to be slower than a mapping with fewer response alternative, but more codes assigned to each response.

8. The finding that the input rate was slower for the separate response mapping early in practice suggests a general principle: the more alternative responses in the response panel, the slower will be the rate of input of information until the performer of the task becomes familiar with the response panel and/or task demands.

9. The more codes that are presented to be identified, and the more complex the task, the slower they will be processed, i.e. the slower the input and the slower the output.

10. The theoretical distinction between input and output appears to be justified given the different empirical findings found for input time and output time as defined by the WiTS procedure.

(This page intentionally left blank.)

CHAPTER 5 - Identification of Codes from Single and Compound Targets.

This chapter summarizes the results from the second of a series of experiments based on the general experimental design described in Chapter 3. The results from the analyses using four target-task comparison will be described where the targets on the display consisted of single digit codes or compound digit-letter codes. The task was to identify *only* digits *or* letters. The central question asked in this study is: Does the presence of irrelevant information codes, (i.e. noise codes), in a target change performance relative to the presence of only relevant codes?

This study will continue to address the problem of how information codes are processed in terms of input and output. The results of the study described in Chapter 4 began to address the question of how codes in display targets are processed by examining the performance seen in identifying single code targets from either of two code categories versus that seen in identifying single code targets from both of two code categories. The first study established that:

1). The identification of two similar subsets of alphanumeric codes (representing either digits or letters), results in differential effects as measured by overall response latency, and, input and output time. It was therefore concluded that digit and letter codes are, in fact, processed differently.

2). The identification of targets in a display that come from two different code categories causes overall latency to be comparable to the most slowly identified component code. Further, the partitioning of overall response time into input and output components revealed that while input time generated the same performance as total time, i.e. the performance seen was comparable to the most slowly

identified of the component codes, output time was significantly slower than that seen for either of the component codes.

Having established that digit and letter codes, though conceptually similar, represent different categories of codes, and that the identification of targets representing both categories causes performance comparable to the most slowly identified of the component categories, it is possible to assess the performance seen in identifying targets with irrelevant codes relative to that seen with only relevant codes.

The specific objectives of this study were to:

1. Continue to demonstrate the utility of the Within-Task Subtractive (WiTS) method of partitioning response time in assessing performance in an identification task and, assess that methodology for the purposes of extending results to applications and theory development.

2. Continue the demonstration and validation of the general approach to assessing display and response codes, and alternative response mappings, as a function of task load in an identification task that was begun in Chapter 4.

3. Assess the relative performance of subjects identifying subsets of codes from each of two single categories when those codes are presented as single code targets versus when those codes are presented as compound targets incorporating an irrelevant (noise) code. In this study four target identification tasks were used. Two tasks required the identification of targets consisting of single codes (digits or letters), and two required the identification of either digits or letters from compound (digit-letter) targets.

4. Continue to assess the impact of alternative response mappings on input and output processing in an identification task. One response mapping had a single alphanumeric code assigned to each of sixteen response buttons. The second had both a digit and letter code assigned to each of eight response buttons. It was suggested that these panels differ in the complexity of their response mappings, and therefore affect performance.

5. Provide an empirical basis for the formulation of predictions analyzed in later experiments, as well as provide a basis for interpreting the results obtained in those studies. This objective is important because the studies described in the following chapters will be based upon the methodology, analysis techniques, and empirical results developed in this study.

DESIGN

The first factor manipulated in this study was the type of target presented in the identification task. Figure 5-1 shows that there were four levels of target/task type assigned as a between-subjects factor. Subjects could: 1) identify digits from targets consisting one digit in each of several cells; 2) identify digits from targets consisting of a digit and a letter in each of several cells (compound targets - identify digits); 3) identify letters from targets consisting of one letter in each of several cells; or 4) identify letters from targets consisting of a letter and a digit in each of several cells (compound targets - identify letters). As described in Chapter 3, the display used consisted of 16 cells arranged in a four-by-four cell matrix. Targets were randomly assigned to cells in the matrix. Compound targets for half the subjects consisted of a digit-letter combination, and for the other half of the subjects consisted of a letter-digit combination. Only eight digit codes (1, 2, 3, 4, 5, 6, 7 and 8) and eight letter codes (A, B, C, D, E, F, G and H) were used. In addition to the Digits, Compound (digits), Letters, Compound (letters) target-task manipulation, two response mappings are employed as a between-subjects factor. The separate response mapping had a unique alphanumeric code associated with each response button. As described in Chapter 3, letters were on the top half of the 16 button response panel and digits on the bottom half of the response panel for half of the subjects, while for the other half of the subjects letters were on the bottom half of the response panel, and digits on the top. All digit and letter codes were mapped to the response keys using an ordinal mapping. The second response mapping, referred to as the compound mapping, had two codes, a digit and a letter, assigned to each of eight response buttons within the response panel. For half the subjects the buttons were labelled with digit-letter combinations, while buttons were labelled with letter-digit combinations for the remaining subjects. Again, the digit and letter codes were assigned with an ordinal mapping.

Figure 5-1. Experimental Design for the Digits, Compound (Digits), Letters, Compound (Letters) Comparison.

	Target-Task Type	Response Mapping	Within Factors			
			Number of Targets:	2	3	4
			Blocks:	1-10	1-10	1-10
Between Factors	Digits	Separate				
		Compound				
	(Compound) Digits	Separate				
		Compound				
	Letters	Separate				
		Compound				
	(Compound) Letters	Separate				
		Compound				

Two manipulations shown in the experiment design (Figure 4-1) were within-subjects factors. The first represented a manipulation of task load, defined by the target density. Either 2, 3 or 4 targets were presented within the 16-cell matrix on the display. The final factor assessed was the number of blocks of practice. Each block represented 30 trials (10 for each of the 2, 3 and 4 target conditions). There were 10 blocks of trials, for a total of 300 trials, for each subject.

The experiment design was a split-plot factorial with two between-subjects factors (target type and response mapping, at four and two levels respectively), and two within-subjects factors (number of targets and blocks, at three and ten levels respectively). This experiment encompassed the data for 80 subjects (10 subjects for each of the between subject conditions). It should be noted that the data from 40 of these subjects was the same as that used for the analyses in Chapter 4. Data for two dependent variables, percent correct and response time for each response is collected. From the response time data, total response time per target, input time per target, and output time per target are calculated using the WiTS methodology, as described in Chapter 3.

The following predictions are described in terms of accuracy, total, input and output time.

1. If there is a difference seen in the performance for identifying digits using the digits only and compound displays, then it is because of a change in processing due to the presence of the irrelevant letter codes. Likewise, if there is a difference seen in identifying letters using the letters only and compound displays, then it is because of a change in processing due to the presence of the irrelevant digit codes in the compound targets. It is reasonable to expect that there would be significant differences between the single and compound targets for accuracy, total and input latencies.

2. It is not expected that there would be effects due to the irrelevant codes in output time, because irrelevant information should not be encoded into memory during input, i.e. the irrelevant codes in the compound targets are filtered out as the relevant codes are encoded. Because the irrelevant codes are from a consistent category, (i.e. letters for compound (digits) subjects, and digits for the compound (letters) category), the irrelevant codes should have a minimal impact on processing, (Egeth, 1988; Proctor & Fober, 1988; Pashler & Baylis, 1991[a,b]). If there is a change in performance as measured by output time due to the presence of irrelevant codes in the targets, then it is because that information has been encoded into memory. If the irrelevant codes affected output, then they must be encoded into memory during input in order to affect output processing. Further, if the irrelevant codes are filtered out or ignored, then there should be no effect on output processing because the irrelevant codes should not be in working memory to have an effect.

3a. If there is a performance difference between the single and compound code targets, and the compound targets result in performance that is approximately half, i.e. less accurate and slower, than that seen in either of the single target tasks, then the irrelevant codes in the compound targets are being processed to the same degree as the relevant targets.

3b. If the composite code set results in performance that is slightly worse than that seen with the single target tasks, then the decrement in performance is probably due to the processing associated with filtering out the irrelevant codes.

4. If the response mapping interacts with target density as measured by any of the latency per target measures, then response mapping affects the way information is processed in an identification task. If there is a significant interaction involving target density and the response mapping for input time per target, then the response mapping affects the way

information is read from a display and encoded into memory. If there is a significant interaction involving target density and the response mapping for output time per target, then the response mapping affects the way information is taken from memory and translated into responses.

5. If the identification task involves a significant component of information processing, then there will be a stereotypic learning curve over blocks for all the dependent measures, and the blocks will show a significant interaction with the target density. Specifically, performance will improve (increase in percent correct; decrease in total, input and output time) with increases in number of blocks. Further, the effect is expected to be non-linear, with the greatest improvement in the first few blocks, and the greatest improvement when there are more targets to be identified.

RESULTS

The basic comparison of the digit and letter codes is performed through a series of multivariate analysis of variance (MANOVA) procedures. All MANOVAS were performed using the Complete Statistical Software (CSS: Statistica) analysis package for MS-DOS computers (Statsoft, 1991). Post-hoc comparisons for significant effects were performed using the Neuman-Keuls procedure (Kirk, 1982; Statsoft, 1991) included as part of this statistical software. A separate MANOVA was performed for each of the dependent variables: Percent Correct, Total Time per target, Input Time per target, and Output Time per target. The results of these analyses are summarized in Table 5-1 and are described in detail below. Based on the results for practice described in Chapter 4, and the finding of significant learning effects during the first three blocks, additional analyses were performed separately for blocks 1-3 and blocks 4-10. These analyses are summarized in Table 5-2 and Table 5-3. The results for all the dependent variables will now be discussed in turn.

Percent Correct. One significant effect was found for the percent correct data in the digits, (compound) digits, letters, (compound) letters conditions over all blocks of data, as shown in Figure 5-2. This was for target density ($F = 8.52$, (2,144), $p < .01$). This effect reflects a significant difference between the four targets conditions (96.0%) and the other conditions (98.4% for the two target conditions and 97.7% for the three targets conditions). The difference in performance was relatively stable across all blocks.

The analyses for blocks 1-3 and 4-10 generated significant main effects for the accuracy of target density as well ($F = 8.52$, (2,144), $P < .01$ for blocks 1-3 and $F = 11.4$, (2,144), $p < .01$ for blocks 4-10). In addition, however, a significant main effect was found for the digits, (compound)

TABLE 5-1. Summary of MANOVA results for Digits, Compound (Digits), Letters, Compound (Letters).[39 40 41]

EFFECT:	% CORRECT:	TOTAL TIME:	INPUT TIME:	OUTPUT TIME:
Condition (C)	$F=2.31,(3,72)$ $p = .083$	$F=6.90,(3,72)$ $p < .01$	$F=7.32,(3,72)$ $p < .01$	$F=3.64,(3,72)$ $p < .05$
Response (R)	$F=3.32,(1,72)$ $p = .073$	$F=0.33,(1,72)$ $p = .565$	$F=0.05,(1,72)$ $p = .820$	$F=0.46,(1,72)$ $p = .500$
C_R	$F=0.16,(3,72)$ $p = .924$	$F=0.94,(3,72)$ $p = .425$	$F=0.82,(3,72)$ $p = .489$	$F=0.65,(3,72)$ $p = .588$
Targets (T)	$F=18.5,(2,144)$ $p < .01$	$F=1622,(2,144)$ $p < .01$	$F=846,(2,144)$ $p < .01$	$F=26.3,(2,144)$ $p < .01$
C_T	$F=0.44,(6,144)$ $p = .849$	$F=7.18,(6,144)$ $p < .01$	$F=5.08,(6,144)$ $p < .01$	$F=1.53,(6,144)$ $p = .174$
R_T	$F=0.03,(2,144)$ $p= .966$	$F=2.74,(2,144)$ $p = .068$	$F=1.36,(2,144)$ $p = .259$	$F=2.52,(2,144)$ $p = .084$
C_R_T	$F=0.19,(6,144)$ $p = .979$	$F=1.01,(6,144)$ $p = .420$	$F=1.23,(6,144)$ $p = .297$	$F=0.73,(6,144)$ $p = .624$
Block (B)	$F=1.09,(9,648)$ $p = .367$	$F=56.3,(9,648)$ $p < .01$	$F=8.94,(9,648)$ $p < .01$	$F=61.1,(9,648)$ $p < .01$

[39] Contrast (C) refers to the comparison of the target-task conditions used in this analysis. Response (R) refers to the response panel mapping effect. Targets (T) refers to the number of targets being identified. Block (B) refers to the number of blocks of practice. Interaction effects are denoted by the abbreviation for the effects separated by an underscore, e.g. C_R indicates the Contrast by Response mapping interaction.

[40] Analysis uses {Digits-Digits-Separate, Digits-Digits-Compound, Compound-Digits-Separate, Compound-Digits-Compound, Letters-Letters-Separate, Letters-Letters-Compound, Compound-Letters-Separate, Compound-Letters-Compound} as groups.

[41] Table based on analyses of- March 18, 1992

C_B	$F = 0.66, (27,648)$, $p = .908$	$F = 1.01, (27,648)$, $p = .448$	$F = 1.32, (27,648)$, $p = .133$	$F = 0.97, (27,648)$, $p = .502$
R_B	$F = 0.78, (9,648)$, $p = .636$	$F = 0.80, (9,648)$, $p = .617$	$F = 0.26, (9,648)$, $p = .984$	$F = 1.03, (9,648)$, $p = .411$
C_R_B	$F = 0.63, (27,648)$, $p = .928$	$F = 0.76, (27,648)$, $p = .802$	$F = 0.91, (27,648)$, $p = .602$	$F = 0.75, (27,648)$, $p = .813$
T_B	$F = 0.82, (18,1269)$, $p = .680$	$F = 3.86, (18,1269)$, $p < .01$	$F = 0.98, (18,1269)$, $p = .483$	$F = 1.03, (18,1269)$, $p = .423$
C_T_B	$F = 0.87, (54,1269)$, $p = .730$	$F = 1.00, (54,1269)$, $p = .420$	$F = 1.28, (54,1269)$, $p = .083$	$F = 0.73, (54,1269)$, $p = .624$
R_T_B	$F = 1.08, (18,1269)$, $p = .362$	$F = 0.86, (18,1269)$, $p = .634$	$F = 0.86, (18,1269)$, $p = .627$	$F = 1.15, (18,1269)$, $p = .292$
C_R_T_B	$F = 0.96, (54,1269)$, $p = .555$	$F = 1.03, (54,1269)$, $p = .423$	$F = 1.03, (54,1269)$, $p = .422$	$F = 1.25, (54,1269)$, $p = .106$

TABLE 5-2. Summary of MANOVA results for Digits, Compound (Digits), Letters, Compound (Letters) - Blocks 1-3 of practice.[42 43 44]

EFFECT:	% CORRECT:	TOTAL TIME:	INPUT TIME:	OUTPUT TIME:
Condition (C)	F=0.86,(3,72) p = .468	F=6.05,(3,72) p < .01	F=7.98,(3,72) p < .01	F=2.86,(3,72) p < .05
Response (R)	F=1.28,(1,72) p = .262	F=0.55,(1,72) p = .460	F=0.16,(1,72) p = .686	F=0.65,(1,72) p = .421
C_R	F=0.14,(3,72) p = .937	F=1.00,(3,72) p = .397	F=0.82,(3,72) p = .489	F=0.68,(3,72) p = .566
Targets (T)	F=8.52,(2,144) p < .01	F=1107,(2,144) p < .01	F=554,(2,144) p < .01	F=5.25,(2,144) p < .01
C_T	F=0.67,(6,144) p = .672	F=4.41,(6,144) p < .01	F=3.05,(6,144) p < .01	F=0.95,(6,144) p = .458
R_T	F=0.76,(2,144) p= .741	F=2.95,(2,144) p = .055	F=2.34,(2,144) p = .100	F=0.39,(2,144) p = .680
C_R_T	F=0.27,(6,144) p = .950	F=1.21,(6,144) p = .304	F=0.48,(6,144) p = .820	F=2.00,(6,144) p = .070
Block (B)	F=2.47,(2,144) p = .088	F=109,(2,144) p < .01	F=23.3,(2,144) p < .01	F=108,(2,144) p < .01

[42] Contrast (C) refers to the comparison of the target-task conditions used in this analysis. Response (R) refers to the response panel mapping effect. Targets (T) refers to the number of targets being identified. Block (B) refers to the number of blocks of practice. Interaction effects are denoted by the abbreviation for the effects separated by an underscore, e.g. C_R indicates the Contrast by Response mapping interaction.

[43] Analysis uses {Digits-Digits-Separate, Digits-Digits-Compound, Compound-Digits-Separate, Compound-Digits-Compound, Letters-Letters-Separate, Letters-Letters-Compound, Compound-Letters-Separate, Compound-Letters-Compound} as groups.

[44] Table based on analyses of- March 18, 1992

C_B	F=0.31,(6,144) p = .932	F=1.12,(6,144) p = .352	F=0.57,(6,144) p = .754	F=1.38,(6,144) p = .228
R_B	F=0.70,(2,144) p = .498	F=0.80,(2,144) p = .451	F=0.08,(2,144) p = .925	F=0.75,(2,144) p = .473
C_R_B	F=1.44,(6,144) p = .204	F=0.43,(6,144) p = .857	F=0.73,(6,144) p = .625	F=0.33,(6,144) p = .919
T_B	F=0.54,(4,288) p = .710	F=5.31,(4,288) p < .01	F=0.41,(4,288) p = .805	F=1.32,(4,288) p = .262
C_T_B	F=0.42,(12,288) p = .957	F=1.19,(12,288) p = .292	F=1.17,(12,288) p = .304	F=0.59,(12,288) p = .848
R_T_B	F=0.53,(4,288) p = .710	F=1.12,(4,288) p = .345	F=0.68,(4,288) p = .604	F=1.81,(4,288) p = .126
C_R_T_B	F=1.55,(12,288) p = .106	F=0.90,(12,288) p = .546	F=0.37,(12,288) p = .968	F=1.74,(12,288) p = .059

TABLE 5-3. Summary of MANOVA results for Digits, Compound (Digits), Letters, Compound (Letters) - Blocks 4-10 of practice.[45 46 47]

EFFECT:	% CORRECT:	TOTAL TIME:	INPUT TIME:	OUTPUT TIME:
Condition (C)	F=2.76,(3,72) $p < .05$	F=7.00,(3,72) $p < .01$	F=6.81,(3,72) $p < .01$	F=3.80,(3,72) $p < .05$
Response (R)	F=3.13,(1,72) $p = .081$	F=0.23,(1,72) $p = .632$	F=0.02,(1,72) $p = .880$	F=0.33,(1,72) $p = .569$
C_R	F=0.29,(3,72) $p = .834$	F=0.92,(3,72) $p = .438$	F=0.84,(3,72) $p = .479$	F=0.60,(3,72) $p = .620$
Targets (T)	F=11.4,(2,144) $p < .01$	F=1608,(2,144) $p < .01$	F=856,(2,144) $p < .01$	F=31.2,(2,144) $p < .01$
C_T	F=0.16,(6,144) $p = .987$	F=7.65,(6,144) $p < .01$	F=5.72,(6,144) $p < .01$	F=1.55,(6,144) $p = .167$
R_T	F=0.67,(2,144) $p= .515$	F=2.13,(2,144) $p = .122$	F=0.84,(2,144) $p = .433$	F=5.17,(2,144) $p < .01$
C_R_T	F=0.56,(6,144) $p = .760$	F=0.83,(6,144) $p = .551$	F=1.59,(6,144) $p = .153$	F=1.11,(6,144) $p = .360$
Block (B)	F=0.84,(6,432) $p = .538$	F=1608,(6,432) $p < .01$	F=1.85,(6,432) $p = .088$	F=5.23,(6,432) $p < .01$

---

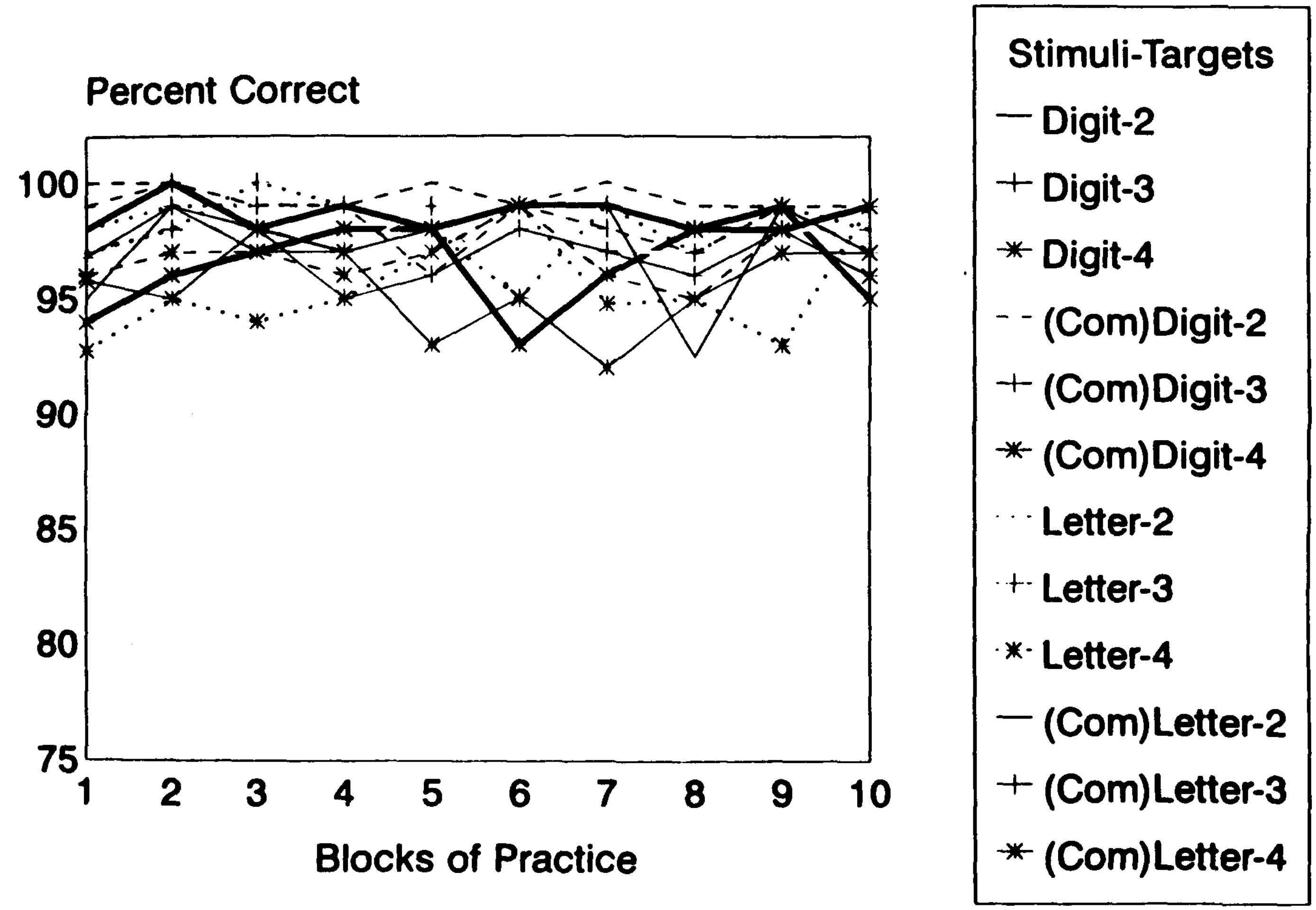
[45]Contrast (C) refers to the comparison of the target-task conditions used in this analysis. Response (R) refers to the response panel mapping effect. Targets (T) refers to the number of targets being identified. Block (B) refers to the number of blocks of practice. Interaction effects are denoted by the abbreviation for the effects separated by an underscore, e.g. C_R indicates the Contrast by Response mapping interaction.

[46] Analysis uses {Digits-Digits-Separate, Digits-Digits-Compound, Compound-Digits-Separate, Compound-Digits-Compound, Letters-Letters-Separate, Letters-Letters-Compound, Compound-Letters-Separate, Compound-Letters-Compound} as groups.

[47]Table based on analyses of- March 18, 1992

C_B	F=0.77,(18,432) p = .740	F=0.74,(18,432) p = .769	F=1.15,(18,432) p = .297	F=1.17,(18,432) p = .279
R_B	F=0.95,(6,432) p = .462	F=0.99,(6,432) p = .434	F=0.36,(6,432) p = .905	F=1.44,(6,432) p = .196
C_R_B	F=0.45,(18,432) p = .976	F=0.79,(18,432) p = .718	F=0.90,(18,432) p = .581	F=1.10,(18,432) p = .352
T_B	F=0.79,(12,864) p = .664	F=1.40,(12,864) p = .159	F=1.14,(12,864) p = .325	F=1.04,(12,864) p = .409
C_T_B	F=1.10,(36,864) p = .320	F=0.94,(36,864) p = .567	F=1.25,(36,864) p = .149	F=0.79,(36,864) p = .806
R_T_B	F=1.18,(12,864) p = .291	F=0.73,(12,864) p = .723	F=0.72,(12,864) p = .736	F=0.72,(12,864) p = .733
C_R_T_B	F=0.87,(36,864) p = .692	F=1.14,(36,864) p = .268	F=1.49,(36,864) p < .05	F=0.69,(36,864) p = .913

Figure 5-2. Digits, Compound (Digits), Letters, Compound (Letters)
Percent Correct



18 March 1992

digits, letters, (compound) letters conditions in blocks 4-10 ($\underline{F}=2.76$, (3,72), $p < .05$). This main effect was due to the digits (which had the worst accuracy at 96.3%) being significantly different from the (compound) digits conditions (which had the best accuracy at 98.0%). Neither the letters condition (97.5%) nor the (compound) letters condition (97.5%) were significantly different from each other or the digits conditions. The very high level of accuracy across all conditions suggests that the sensitivity of the percent correct measure may be reduced due to a ceiling effect.

Total Time. Figure 5-3 illustrates significant total time main effects for the target-task comparison ($\underline{F}=6.90$, (3,72), $p < .01$), target density ($\underline{F}=1622$, (2,144) $p < .01$), and blocks ($\underline{F}=56.3$, (9,648) $p < .01$). The target-task main effect is due to the digits (2767 msec. per target) and (compound) digits (2956 msec. per target) being significantly faster than the letters (3379 msec. per target) and (compound) letters (3357 msec. per target) conditions. The overall time per response was longer, i.e. the rate of responding was slower, for those conditions which had more targets to be identified, (2099, 3076, 4169 msec. per target for the 2, 3 and 4 target conditions). The significant block effect reflects a significant drop in response time after the first block (3595 msec. per target for block 1 versus an average of 3100 msec. per target for the remaining blocks).

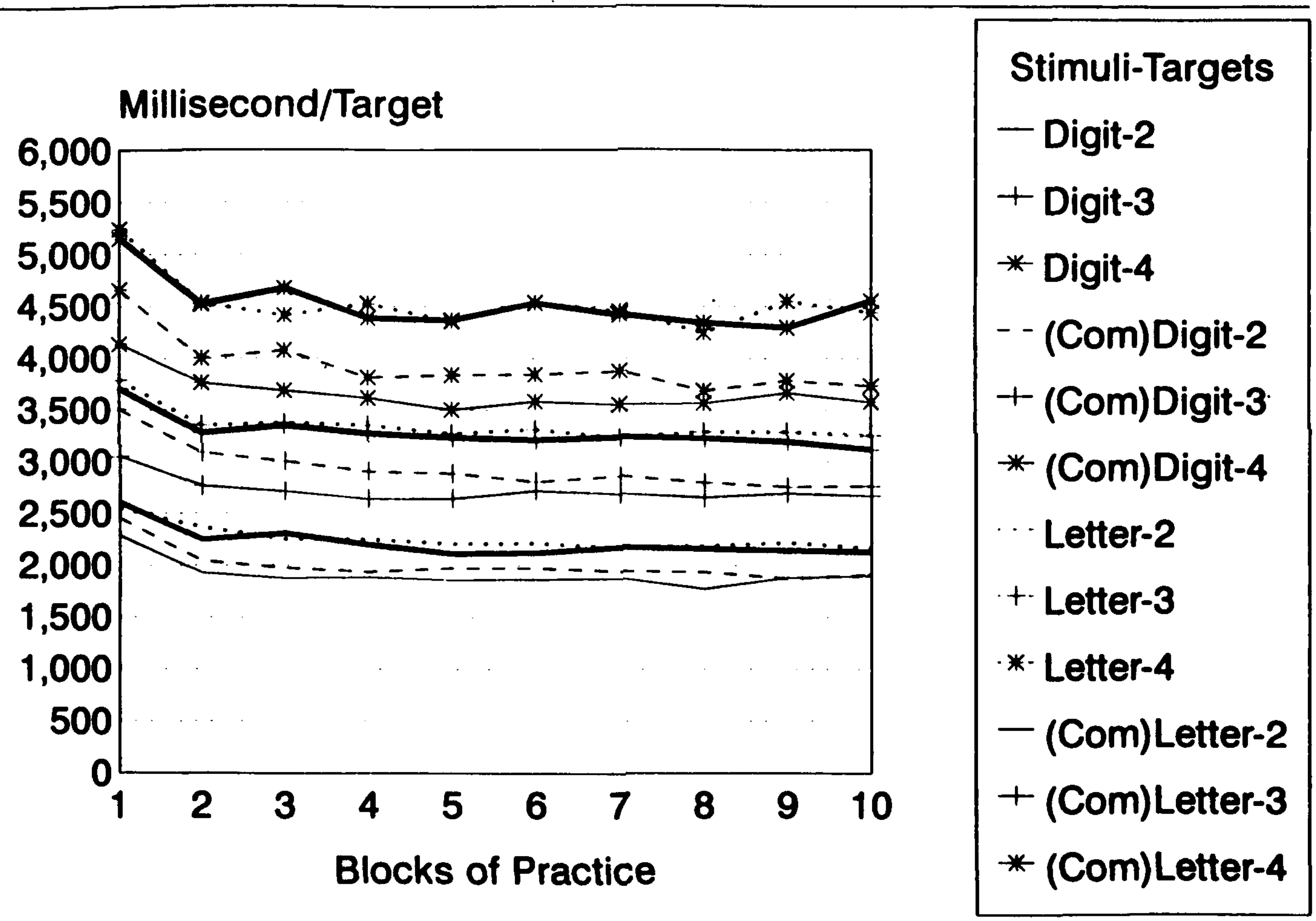
There were two significant two-way interactions for the analysis of total time over all blocks. The first was for the target-task conditions and target density ($\underline{F}=7.18$, (6,144), $p < .01$). This interaction, illustrated in Figure 5-4, reflects a greater improvement for the letters and (compound) letters conditions between blocks 1 and 10 than there were for the digits and (compound) digits conditions. The regressions:

$$\text{Total Time}_{\text{Digits}} = 876.7\ (\text{Number of Targets}) + 158.1,$$

$$\text{Total Time}_{\text{Compound (Digits)}} = 965.0\ (\text{Number of Targets}) + 71.0,$$

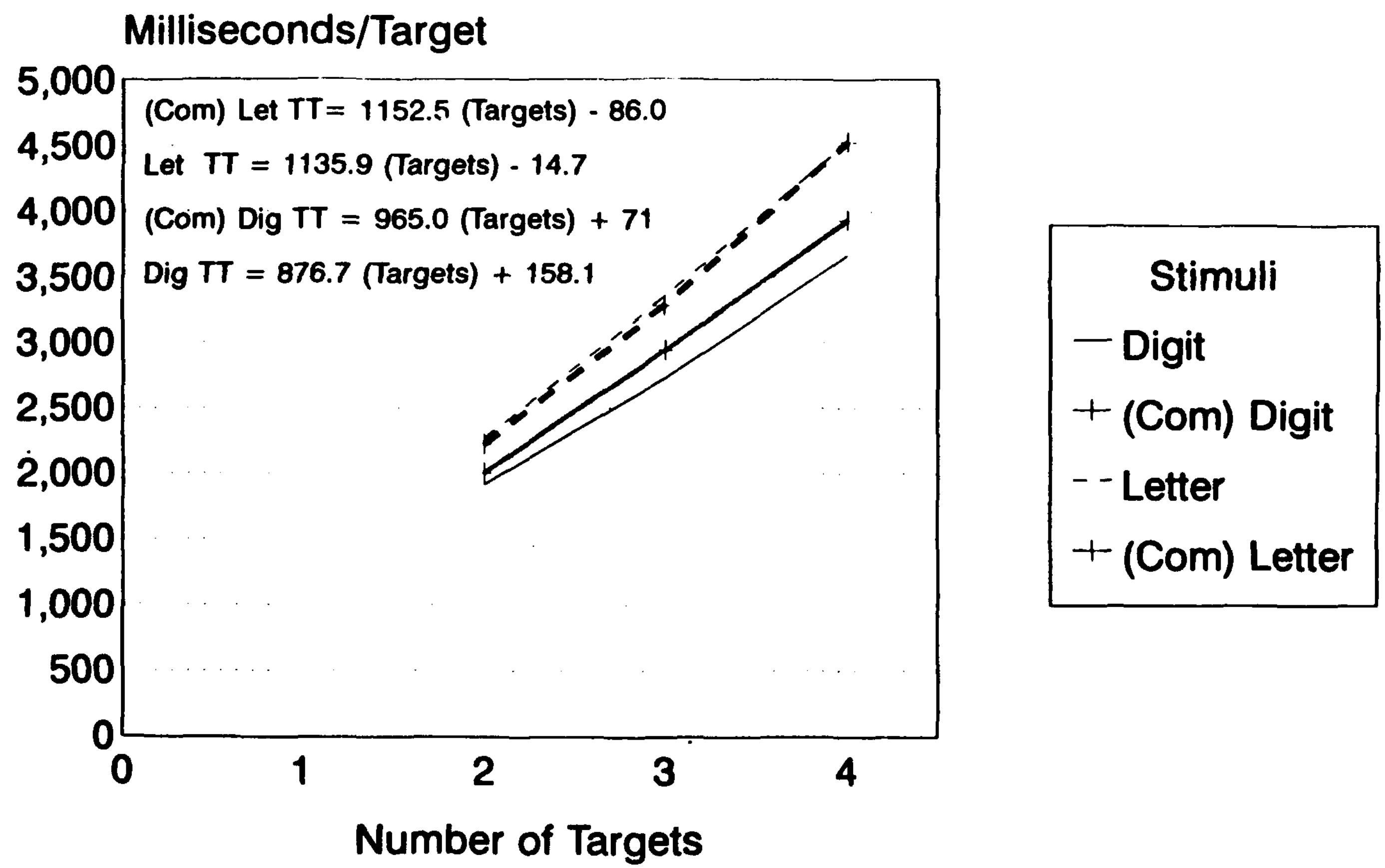
$$\text{Total Time}_{\text{Letters}} = 1135.9\ (\text{Number of Targets}) - 14.7,$$

Figure 5-3. Digits, Compound (Digits), Letters, Compound (Letters): Total Time



19 March 1992

Figure 5-4. Digits, Compound (Digits), Letters, Compound (Letters): Total Time Stimulus-Task by Number of Targets Interaction.



20 March 1992

$$\text{Total Time}_{\text{Compound (Letters)}} = 1152.5 \text{ (Number of Targets)} - 86.0,$$

reflect the rate of change in identification for each of the target-task conditions as a function of the target density. From these regressions it appears that the rate of identification for the letter conditions decreased approximately 460 msec. per target^2 faster than did digits. The post-hoc Neuman-Keuls for the interaction indicated that:

1) when the target density was two targets, digits and compound (digits) were not significantly different from each other, but were significantly different from both letters and compound (letters), which were not different from each other;
2) when the target density was three targets, digits were significantly different from compound (digits), both of which were different from letters and compound (letters), however letters and compound (letters) were not significantly different from each other;
3) when the target density was four targets, digits and compound (digits) were not significantly different from each other, but were significantly different from both letters and compound (letters), which were not different from each other.

The second significant interaction for total time per target over all blocks was for the target density and blocks manipulations ($\underline{F}$=3.86, (18,1269), $p < .01$). This interaction, as seen in Figure 5-3, reflects the rate of processing improving significantly more with practice when more targets were being identified.

The analyses for the first three and final seven blocks generally revealed the expected significant effects, i.e. the same pattern of main effects and interactions for blocks 1-3 and a loss of most of the practice effects for blocks 4-10. The analysis for the total time in blocks 1-3 generated significant effects for the target-task comparison ($\underline{F}$=6.05, (3,72), $p < .01$), target density ($\underline{F}$=1107, (2,144), $p < .01$), blocks ($\underline{F}$=109, (2,144), $p < .01$), and the comparison by target density ($\underline{F}$=4.41, (6,144), $p < .01$) and target density by blocks interactions ($\underline{F}$=5.31, (4,288), $p < .01$). The significant

differences which caused these effects were also the same as those seen for all blocks. The letters and (compound) letters target-task conditions (3542 msec. per target, 3557 msec. per target) were significantly slower than the digits and (compound) digits conditions (2912 msec. per target and 3200 ,sec. per target). All three levels of target density were significantly different from each other (2243, 3250 and 4413 msec. per target for the 2, 3 and 4 targets conditions). All three blocks early in practice were significantly different from each other (3601, 3161, and 3146 msec. per target for blocks 1, 2 and 3).

In blocks 4-10, there was a significant main effect for the target-task comparison ($\underline{F}$=7.00, (3,72), $p < .01$) where the digits (2704 msec. per target) and compound (digits) (2851 msec. per target) were identified more rapidly than the letters (3309 msec. per target) and compound (letters) (3272 msec. per target). There was also a significant main effect for target density ($\underline{F}$=856, (2,144), $p < .01$), where the 2, 3 and 4 targets conditions were all different from each other (2038, 3001 and 4064 msec. per target). There was a significant target-task comparison by target density interaction effect similar to that seen in the analysis over all blocks, and shown in Figure 5-4. There was also an unexpected blocks effects main effect in the analyses of the total time data from blocks 4-10 ($\underline{F}$=1608, (6,432), $p < .01$). It apparently resulted because block 8 (2990 msec. per target) was significantly faster than block 4 (3068 msec. per target).

Input Time. The significant effects for input time per target over all blocks were the same as those found for total time per target. The data, shown in Figure 5-5, generated a significant main effect for the target-task comparison ($\underline{F}$=7.32, (3,72), $p < .01$) where the digits and compound (digits) conditions (1636, 1756 msec. per target) were significantly different from the letters and compound (letters) conditions (1951, 2053 msec. per target). All three levels of the target density were significantly different from each other ($\underline{F}$=846, (2,144), $p < .01$; 1291, 1823 and 2432 msec. per target for the 2, 3 and 4 targets conditions). The first block of practice (1983 msec. per target) was

Figure 5-5. Digits, Compound (Digits), Letters, Compound (Letters): Input Time

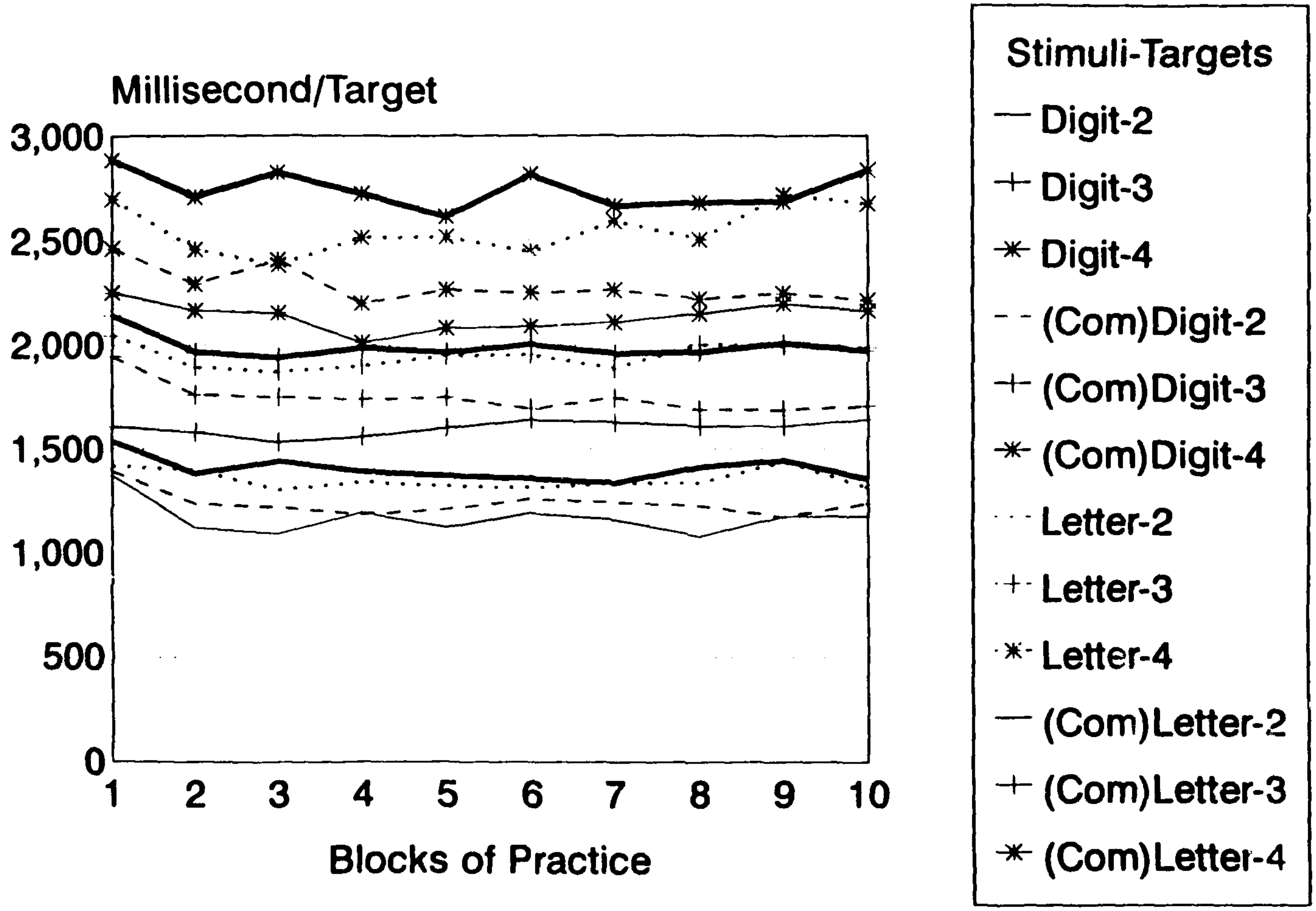
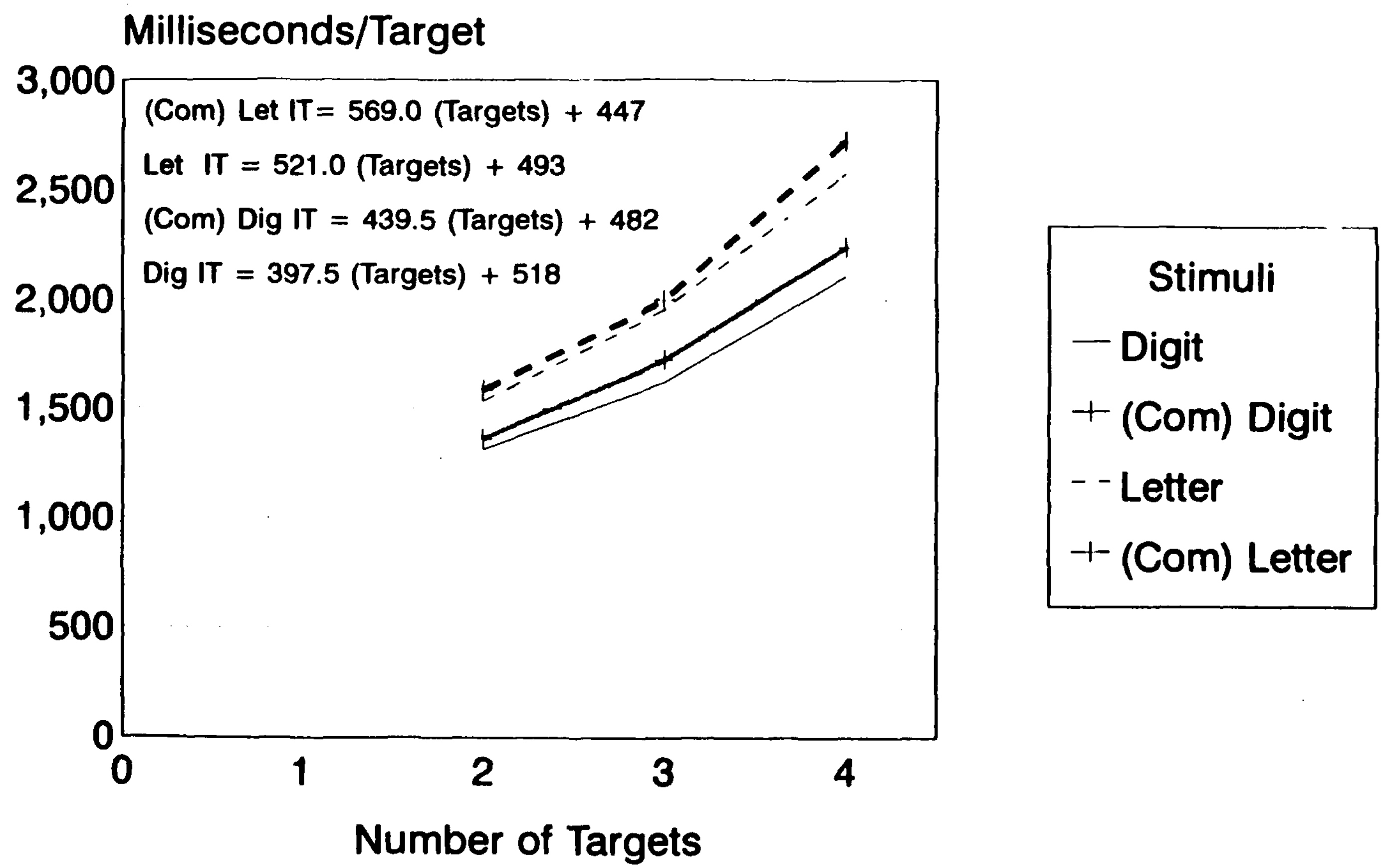


Figure 5-6. Digits, Compound (Digits), Letters, Compound (Letters): Input Time Stimulus-Task by Number of Targets Interaction.



20 March 1992

significantly different than all other blocks (an average of 1847 msec. per target) for input time ($F=8.94$, (9,648), $p < .01$). Further, there was one significant interaction for input time per target over blocks 1-10, and that was for the target-task comparison and target density ($F=5.08$, (6,144), $p < .01$). Figure 5-6 illustrates this interaction. The interaction resulted because letter conditions generated a significantly higher increase in input time per target as the number of targets increased. The regressions for the four target-task conditions are:

$$\text{Input Time}_{\text{Digits}} = 397.5\ (\text{Number of Targets}) + 518.0,$$

$$\text{Input Time}_{\text{Compound (Digits)}} = 439.5\ (\text{Number of Targets}) + 482.0,$$

$$\text{Input Time}_{\text{Letters}} = 521.0\ (\text{Number of Targets}) + 493.0,$$

$$\text{Input Time}_{\text{Compound (Letters)}} = 569.05\ (\text{Number of Targets}) + 447.0.$$

The post-hoc Neuman-Keuls test for the target-task by density interaction indicated exactly the same pattern of results seen for this interaction in total time per target. Specifically:

1) when two targets were being identified, digits and compound (digits) were not significantly different from each other, but were significantly different from both letters and compound (letters), which were not different from each other;
2) when three targets were being identified, digits were significantly different from compound (digits), both of which were different from letters and compound (letters), however the letters and compound (letters) conditions were not significantly different from each other;
3) when four targets were being identified, digits and compound (digits) were not significantly different from each other, but were significantly different from both letters and compound (letters), which were not different from each other.

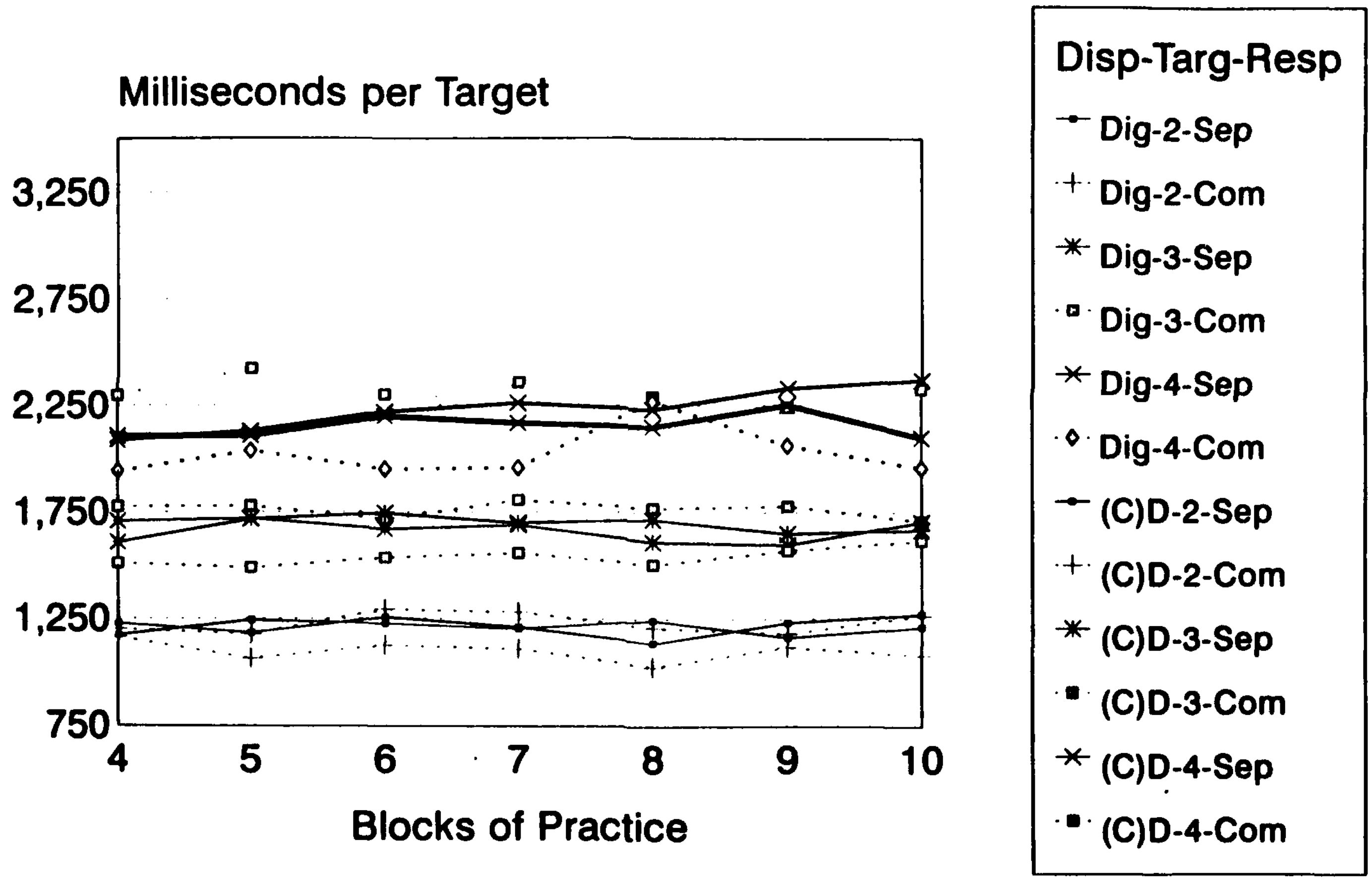
The analyses for blocks 1-3 and 4-10 effectively confirmed the results for the overall analysis of input time, and the assertion that learning is essentially completed by block 4, with one caveat

that will be described below. The analysis for blocks 1-3 generated significant main effects for the target-task comparison (F=7.98, (3,72), $p < .01$), the target density, (F=554, (2,144), $p < .01$), and blocks (F=23.3, (2,144), $p < .01$). Again, the digits and compound (digits) conditions were significantly different from the letters and compound (letters) conditions. All three levels of target density were significantly different from each other in the first three blocks. Only block 1 was significantly different from blocks 2 and 3, as would be expected based on the results of the overall analysis of input time. Finally, there was one significant interaction for input time over blocks 1-3, and that was for the target-task manipulation by target density.

The results for input time per target over blocks 4-10 was somewhat more complex than was anticipated from the analysis over blocks 1-10. There was the expected significant main effects for the target-task comparison (F=6.81, (3,72), $p < .01$), and number of targets (F=856, (2,1144), $p < .01$). The digit conditions again proved significantly different from the letter conditions (1628, 1724, 1955 and 2032 msec. per target for the digits, compound (digits), letters and compound (letters) conditions respectively). The 2, 3 and 4 targets conditions were all significantly different from each other (1276, 1816 and 2413 respectively). Further, there was the expected significant target-task comparison by number of targets identified interaction effect (F=5.72, (6,144), $p < .01$). Unexpected was a significant four-way interaction for the target-task by response mapping by density by blocks effects in the input time data for blocks 4-10. This effect, shown in Figures 5-7a and b, apparently occurred with the identification of the compound (letters) targets, when four targets were being identified using the compound response mapping in block 10 of practice.

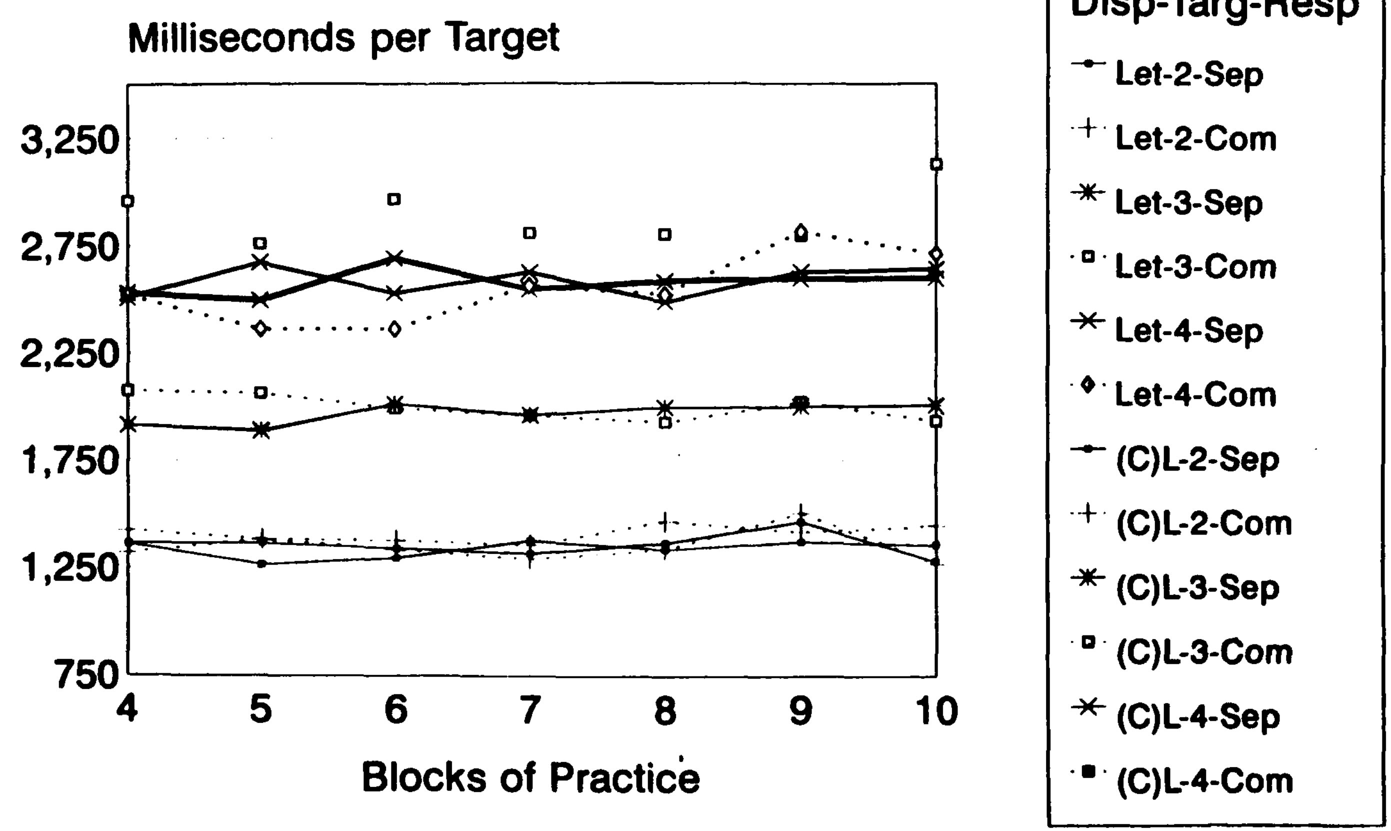
Output Time. The analysis of output time per target for blocks 1-10 (Figure 5-8) revealed three significant main effects. The target-task comparison effect revealed that the output of the letters condition was significantly slower (471 msec. per target) than the digits and compound (digits) conditions (375, 396 msec. per target), and the same as the compound (letters) conditions (430 msec.

Figure 5-7a. Digits, Compound (Digits), Letters, Compound (Letters): Input Time - Blocks 4-10 Interaction for Contrast by Response Mapping by Number of Targets



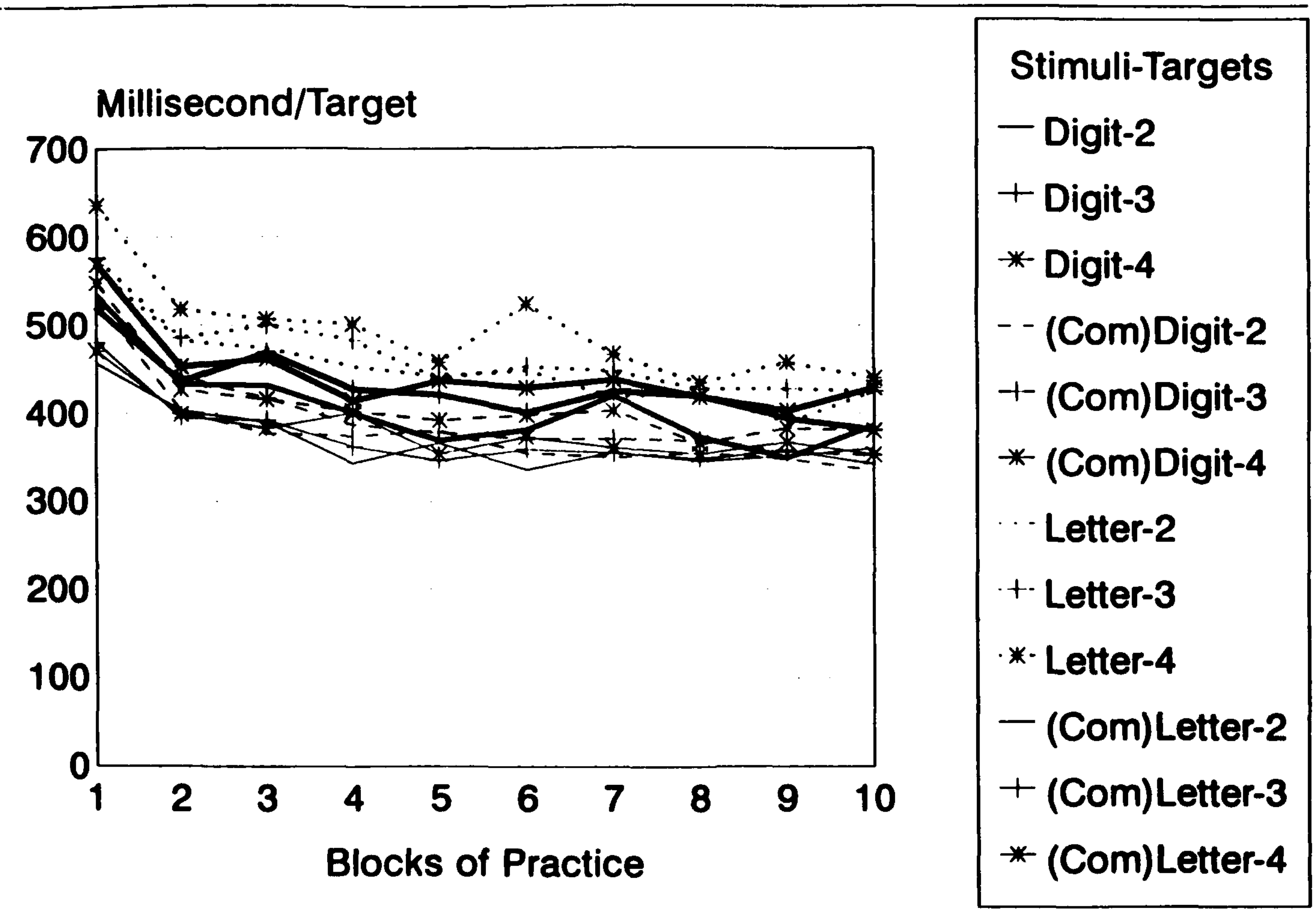
20 March 1992
Graph 1 of 2

Figure 5-7b. Digits, Compound (Digits), Letters, Compound (Letters): Input Time - Blocks 4-10 Interaction for Contrast by Response Mapping by Number of Targets



20 March 1992
Graph 2 of 2

Figure 5-8. Digits, Compound (Digits), Letters, Compound (Letters): Output Time



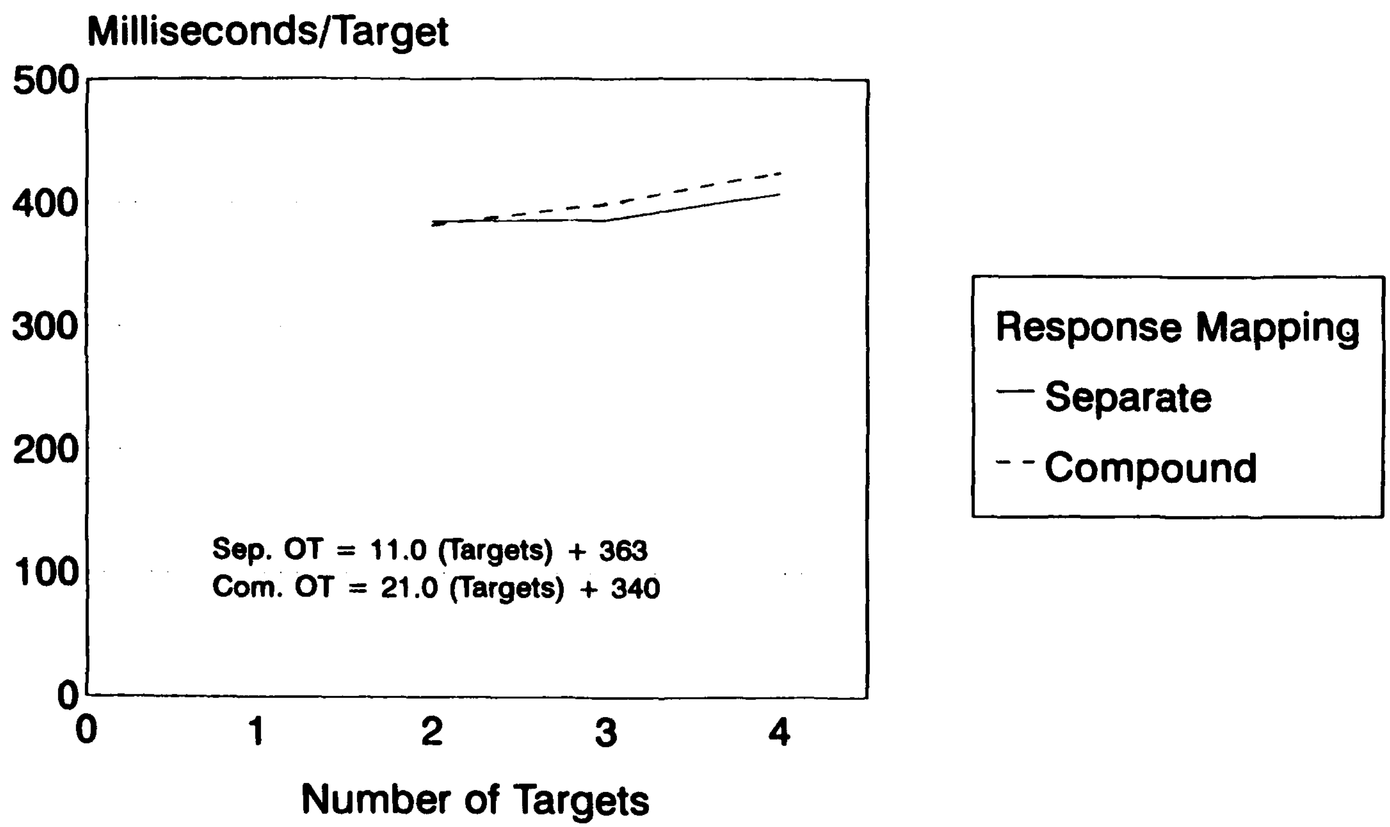
19 March 1992

per target). All three density conditions were significantly different from each other ($\underline{F}$=26.3, (2,144), $p < .01$; with 404, 417, and 434 msec. per target for the 2, 3 and 4 targets conditions). Finally, blocks 1, 2, and 3 proved significantly different from blocks 4-10 ($\underline{F}$=61.1, (9,648), $p < .01$).

The analyses for blocks 1-3 and 4-10 essentially confirmed the expected practice effects. Blocks 1-3 had significant main effects for the target-task comparison ($\underline{F}$=2.86, (3,72), $p < .05$), density ($\underline{F}$=5.25, (2,144), $p < .01$), and blocks ($\underline{F}$=108, (2,144), $p < .01$). The letters target-task condition (527 msec. per target) was significantly different from the digits (419 msec. per target), compound (digits) (453 msec. per target) and compound (letters) conditions (482 msec. per target). The 2 targets condition (456 msec. per target) was significantly faster in the first three blocks than the 3 or 4 targets conditions (470 and 483 msec. per target). All three blocks were significantly different from each other (535, 441 and 436 msec. per target for blocks 1, 2, and 3).

The output time for blocks 4-10 showed one significant interaction. and three main effects. The target-task comparison was significant because the output of the two digits conditions were significantly different from the two letter conditions ($\underline{F}$=3.80, (3,72), $p < .05$; 357, 372, 447 and 408 msec. per target for the digits, compound (digits), letters and compound (letters) conditions). The target density manipulation was significant at all three levels, ($\underline{F}$=31.2, (2,144), $p < .01$; 380, 395 and 413 msec. per target for the 2, 3 and 4 targets conditions). Somewhat surprising for the data from blocks 4-10 was a significant main effect for blocks ($\underline{F}$=5.23, (6,432), $p < .01$). This effect resulted because output performance was still significantly improving for blocks 4-7, which were significantly different each other and from blocks 8, 9 and 10 (the mean output time per target for blocks 4-10 were: 413, 399, 403, 402, 386, 383 and 384). The significant interaction effect was for the response mapping by target density ($\underline{F}$=5.17, (2,144), $p < .01$). As may be seen in Figure 5-9, this effect is due to the output time per response increasing with an increase in the target density. The rate of increase was twice as fast for the compound response mapping as it was for the separate response

Figure 5-9. Digits, Compound (Digits), Letters, Compound (Letters): Output Time - Response Mapping by Number of Targets Interaction
Blocks 4-10



20 March 1992

mapping (21.0 msec. per $Target_2$ for the compound response mapping versus 11.0 msec. per $target_2$ for the separate response mapping). The Neuman-Keuls test for this interaction showed that there were significant differences in the response mapping when three or four targets were being identified. The functions seen in Figure 5-9 are described by the equations:

$$\text{Output Time}_{\text{Separate}} = 11.0\ (\text{Number of Targets}) + 363.0$$

$$\text{Output Time}_{\text{Compound}} = 21.0\ (\text{Number of Targets}) + 340.0.$$

DISCUSSION

The analyses for the digits, compound (digits), letters and compound (letters) condition confirmed the study in Chapter 4, and the significant difference in identification of digits and letters. Because the study conducted in Chapter 4 demonstrated that there were significant differences for the identification of digits, letters and separate digits and letter codes, the impact of including irrelevant codes in targets in an identification task is more complex. Given the difference between digits, letters, and digits and letters together on the same display, it is reasonable to expect that the performance effects seen by including irrelevant codes when digits are being identified could be different from the performance effects seen by including irrelevant codes when letters are being identified. The bottom line, based on the results described above, is that the presence of irrelevant codes in the targets does affect performance, and the nature of the effect is dependent on the particular category of code being identified.

The assessment of performance accuracy in this study, as was the case with the previous study, requires some caution. The percent correct data is very close to 100%, which corresponds to the maximum limit of the scale. It could therefore be argued that the significant effects found in the percent correct data, as well as the other performance indices, were affected by an accuracy ceiling effect. This means that the sensitivity of the percent correct data in assessing accuracy may be artificially enhanced or suppressed due to the nature of the percent correct scale, and therefore the effects seen may not be representative of actual performance. Further, due to the tendency for an interrelationship between speed of responding, as indicated by the latency measures, and accuracy, measured by the percent correct data (Pachella & Pew, 1968; Pachella, 1974), the latency measures may be affected as well. However, the magnitudes and consistency of the findings suggest that a ceiling effect has not seriously impacted this study, and therefore the results will be interpreted

below without further mention of this issue. Table 5-4 summarizes the actual and relative changes in each of the significant latency main effects, and will serve as the basis for much of the remaining discussion.

Dependent Measures

Percent Correct. The percent correct data served as an indicator of performance accuracy in this study. The accuracy was affected by the different types of target-tasks. Specifically, the digits condition proved to be less accurate than the compound (digits), letters and compound (letters) conditions once the performance differences due to learning had stabilized, as shown by the significant main effect for the target-task comparison in the percent correct data from blocks 4-10. Therefore, it can be speculated, based on the percent correct data, that one effect of including irrelevant codes in a display for a target identification task is to cause subjects to identify targets more accurately than they might otherwise. However, because this effect was found only for the identification of digits, the benefits for accuracy in including irrelevant codes may be limited to only certain categories of target codes in an identification task, e.g those categories of code symbols which lend themselves to rapid identification.

Total Time per Target. The latency data showed that both the digits and compound (digits) conditions were identified significantly more quickly than were the letters or compound (letters). There were no statistically significant differences in the main effect for the target-task comparison between tasks with irrelevant codes and the corresponding tasks without irrelevant codes in the display, i.e. compound (digits) versus digits, and compound (letters) versus letters. However, the significant target-task by target density interaction not only confirmed the significant differences between the digits and letters conditions, but also proved that the compound (digits) were identified more slowly than the digits when two targets were being identified. Thus, the identification of digits

Table 5-4. Digits, Compound (Digits), Letters, Compound (Letters): Differences for Significant Latency Main Effects.

Significant Effect	Total Time Actual Change	Total Time % Change	Input Time Actual Change	Input Time % Change	Output Time Actual Change	Output Time % Change
Comparison:						
Digits-(Com.) Digits	189	6.8%	120	7.3%	21	5.6%
Digits-Letters	612	22.1%	315	19.3%	96	25.6%
Digits-(Com.)Letters	574	20.1%	410	25.1%	52	13.9%
(Comp.) Digits-Letters	423	14.3%	195	11.1%	75	18.9%
(Comp.) Digits-(Comp.) Letters	385	13.0%	290	16.5%	31	7.8%
Letters-(Com.) Letters	-38	-1.0%	95	4.9%	-44	-10.3%
Targets: 2-4	2065	98.5%	1137	88.1%	30	7.4%
Blocks: 1-10	-578	-19.2%	-123	-6.6%	-150	-39.1%

Actual Time in MSec./Target. Group means used to generate this Table may be found in Appendix B.
% Change = Actual Change / (Larger of the Mean Times for that Comparison) * 100.
30 July 1992

was slower when done in the presence of irrelevant codes. While, there was no significant difference between the digits and compound (digits) when four targets were being identified, this may be due to the increased variability of performance as in the conditions with higher target density. The regressions for the target-task by target density interaction show that the rate of increase in total time per target is different for the digits, compound (digits) and both letters conditions. Therefore, it can be concluded that the presence of irrelevant codes in a targets slows down the rate of identification of certain categories of targets, and this effect occurs even when the noise code symbols and noise code category are totally irrelevant to the identification task, in contrast to the suggestions of Proctor & Fober, 1988 and Pasher & Baylis, 1991[a,b].

Having established that the compound (digits) and digits conditions are processed differently both in terms of speed of identification and accuracy, it is of interest to speculate on the potential aspects of processing that might be generating these effects. Comparing the rates of increase in total time per target for the digits, compound (digits), letters and compound (letters) as indicated by the slopes for the regressions in Figure 5-4, it may be seen that the slope for the compound (digits) regressions is approximately midway between that seen for the digits and letters conditions. This suggests that the additional processing imposed by the irrelevant codes in the compound targets is not qualitatively the same as that imposed by the identification of relevant targets. If the relevant and irrelevant codes were processed the same, it would be expected that the slope for the compound (digits) would be twice that for the digits alone, clearly that is not the case. Therefore, the change in processing due to the use of compound targets in the identification of digits is probably due to a qualitative change in processing which causes the digits not only to be identified more slowly, but also more accurately.

Input & Output Time per Target. The partitioning of total time per target into input and output time per target retained the differences between the digits, compound (digits), letters and compound

(letters) conditions. Both input and output time generated the same significant main effects for the target-task conditions, i.e. the letters and compound (letters) conditions were comparable to each other and significantly slower than the digits and compound (digits), which were also equivalent to each other. Input time per target and output time per target showed different results with regard to the target-task conditions by target density interaction. The results for input time per target were of a smaller magnitude than those seen for total time, but retained an identical pattern of significant differences between the target-task conditions as a function of target density. Further, the relative change (as described by percentage of change in Table 5-4), was the same for total time per target and input time per target. This was not the case for output time per target. Thus, the significant difference for the identification of compound (digits), (by virtue of the target-task by number of targets interaction for input time, and no effect for the compound targets in output time), suggests that the impact of the presence of irrelevant code, when present, is due to the reading of targets in the display and the encoding of information into memory as opposed to the taking of information from memory, translating it to and then executing the responses. This is in keeping with the definitions of input and output processing offered by Teichner (1977, 1978).

In addition to the interaction effects described above, the target density manipulation showed significant main effects for all four dependent measures. As more targets were presented, accuracy decreased significantly when four targets had to be identified. The rate of responding decreased significantly for all levels of the number of targets manipulation. The effects were linear functions of the target density, as may be seen in Figures 5-4 and 5-6. Therefore, because total, input and output time are rate measures in this study, it may be concluded that the more targets being identified, the more time consuming is the processing required. Further, the increase in time required reflects the processing required to read targets from the display, encode them into memory, and then, take the targets from memory and translate them to correct responses. The significant interactions between the target-task conditions and target density, for both total time per target and

input time per target has further implications for the nature of the processing required in this task. The overall rate of identification, as indicated by total time, decreased faster for the letters and compound (letters) as the number of target increased, than it did for the digits and compound (digits) conditions. This finding was expected based on the results in Chapter 4, and since performance became less accurate and slower with an increase in the target density, this suggests that the process of identifying letters is somehow less efficient than that for identifying digits.

The response panel mapping showed minimal effects in this study, though it did become involved in one input time interaction, and one output time interaction late in practice. The analysis of data from blocks 4-10 shows that after the initial learning, there was a target-task by response mapping by target density by blocks of practice effect for input time, and a response mapping by target density interaction for output time. The input time interaction reflects a significantly higher input time per target in block 10 for the identification of four, (compound) letter targets using the compound response mapping. The output time interaction shows that the rate of decrease in output for the compound response mapping as the number of targets increased was twice that for the separate response mapping (as indicated by the regression slopes in Figure 5-9). This finding is consistent with the response mapping by target density interaction found in Chapter 4. Clearly then, the mapping of two codes to a single response slows the rate of responding, and the impact of that reduction in output becomes more problematic as more targets (and therefore responses) must be made.

The input time interaction involving response mapping can be explained if the condition where four, (compound) letter targets, using the compound mapping, is considered to be one of the most difficult. This intuitively makes sense due to the high target density, the high number of codes to be read from the display and processed (i.e. both relevant and irrelevant codes) and the complex response mapping. If this condition is accepted as among the most difficult to perform, then it may

be speculated that this result was due to subject fatigue after extensive time on task. The presence of this significant interaction, subtle though it is, supports the proposition that the response side of the task can and does impact the way information is read in from a display and encoded into memory. However, if this is a fatigue factor, the effect would best be described as slowing down the overall rate of input, rather than affecting the nature of processing per se. This effect would be incorporated as part of the a or arousal term of the Teichner model (Teichner, 1977, 1978; Teichner & Williams, 1977).

The effects due to time on task, defined by the number of blocks manipulation, showed significant main effects for all the latency measures. The analyses for blocks 1-3 showed significant reductions in latency, or increases in the rate of identification through the first three blocks. Surprising, however, were the significant main effects for practice found in blocks 4-10 for total time per target and output time per target. The block effect in total time per target resulted from a significant increase in the rate of identification in block 8 relative to blocks 4-7 and 9-10. This increase was relatively small in magnitude, and may be tied to the significant practice effect for output time. The block effect for output time resulted because targets were responded to significantly faster in block 7 than they were in the other blocks in the analysis of output time for blocks 4-10. Further, an examination of the trend in performance over blocks 4-10 shows that there was a fairly consistent improvement in performance through blocks 4-7. Thus, the significant difference in block 7 is attributed to a continuation of the learning effect seen in blocks 1-3. It is probable that the significant difference found in total time per target for block 8 is due to a gradual, cumulative improvement of both input and output performance through blocks 4-8, however the effect was so gradual that the trend did not generate a more persuasive main or interaction effect.

Summary of Results

The results for each of the experimental predictions are summarized below:

1. There were significant differences in performance due to the presence of irrelevant codes in targets when identifying digits as measured by both accuracy and all three latency measures, therefore, the processing of targets is affected by the presence of irrelevant letter codes. The direction of performance changes seen in the digits suggest that the presence of irrelevant codes in digits identification had the effect of making digit identification performance more like that seen with letters, and the separate target conditions described in Chapter 4.

   With regard to the identification of letters in the presence of irrelevant digit codes, there were no significant differences in the accuracy, total time per target, or output time per target measures for the identification of letters from single letter targets versus identifying letters from compound digit-letter targets, suggesting that the presence of irrelevant codes does not affect the identification of letter targets. However, there was evidence for a very subtle interaction effect for input time per target. This is attributable to a four-way interaction in the analysis of input time per target for blocks 4-10 between the target-task conditions, response mapping, target density and blocks. The effect arose due to a significant drop in performance in block 10 for the identification of compound (letters) using the compound response mapping. In effect, this interaction suggests that the presence of irrelevant codes in the identification of letters contributed to a significant fatigue effect late in practice. It is speculated that this condition is more difficult than other conditions because of the specific target-task, number of targets, and response mapping combination involved, and therefore fatigue was found in this condition before it was detected in the other target-task, target density and response mapping combinations. With additional blocks this effect would therefore appear in the results for the other target-task conditions. Thus,

though a very subtle effect, this interaction shows that the presence of irrelevant digit codes in the identification of letters can impact input processing. Though the effects due to the presence of irrelevant codes is very different in the identification of digits and letters, prediction 1 is confirmed for both the digits and letters codes.

2. While significant differences were found in output time for the identification of digits versus the identification of letters, as was expected based on the findings of Chapter 4, there were no significant differences between the digits and compound (digits) or letters and compound (letters) conditions. This means that prediction 2 cannot be rejected based on the empirical data. Therefore, it is reasonable to suggest that irrelevant codes are filtered in the course of input processing and are not encoded into memory, though they may affect processing by raising the level of arousal (the a term in the Teichner model) and thus affect output by increasing the rate of responding.

3. Prediction 3a and 3b concerned the magnitude of processing differences found between the identification of single targets and compound targets with relevant codes, if significant differences were found. As prediction 1 was proven true, and significant differences were found for the identification of digits and compound (digits), predictions 3a and 3b can be addressed. Prediction 3a, stated that if the order of magnitude for the difference between the single target and the compound target with an irrelevant code was on the order of twice as long, that the processing of the two codes in the compound target must be comparable, and that in fact each code constituted a unique target. The examination of Figures 5-4 for total time per target, and Figure 5-6 for input time per target, as well as the relative differences reported in Table 5-4, show that the relative cost for identifying digits from compound targets is approximately half again the time required for identifying digits from single targets. This effectively confirms prediction 3a, and it can be concluded that the

processing effects from irrelevant codes are due to filtering the codes during input rather than the encoding of the irrelevant codes into memory. Thus while the noise codes receive processing during input, the processing is qualitatively different for the noise codes than it is for the relevant code symbols.

4. Prediction 4 related to the impact of the response mapping on total, input and output time per target. It stated that: If the response mapping shows a significant interaction with the target density as measured by one or more of the latency measures, then the response mapping affects the way information is processed in an identification task. There was a significant interaction in the final seven blocks of practice (blocks 4-10) between target density and the response mapping effect in the output time data. Therefore, prediction 4 is confirmed with regard to the translation of information in memory to responses and the execution of those responses. Further, the regressions shown in Figure 5-9 suggest that the rate of identification with compound response mappings slows twice as fast as that seen with the separate response mapping. Therefore, as more targets are identified, the slower the output with the compound mapping relative to the separate response mapping. This finding is consistent with that seen in Chapter 4 for output time, except that the effect was found through all blocks in those analyses. Finally, the impact of response mapping is not demonstrated with regard to total time per target or input time per target. This shows that there are differences between performance as measured in input and output processing.

5. As with the study described in Chapter 4, the effects found due to the manipulation of target density were persistent throughout the experiment, and pervasive across the dependent measures. There was a significant main effect for target density and percent correct, as well as total, input and output time per target. Accuracy decreased as the target density increased, and the rate of identification decreased as that density increased for

overall, input and output processing. In addition, as described above, there were a variety of significant interaction effects involving the target density manipulation. Therefore, in accordance with prediction 6, it is concluded that the target density is a direct manipulation of the amount of information processed in an identification task.

Objectives

This study continued to address the theoretical, methodological and application objectives which were addressed in Chapter 4. These objectives will now be reviewed. The first objective was to assess the utility of the Within-Task Subtractive (WiTS) method of partitioning response latency in assessing performance in an identification task, and its utility in extending the results from such a study to theoretical and application concerns. Chapter 4 showed that there were significant differences with regard to the input and output processing of single element targets from both single and multiple code categories, i.e. the comparison of digits, letters and separate targets. The use of the WiTS methodology demonstrated that measurement of input and output time per target allowed the differences in performance due to the manipulation of the codes being identified to be attributed to the input and/or output aspects of processing. The use of a WiTS methodology allowed a number of subtle effects with regard to the manipulation several factors traditionally manipulated in the study of processing. One factor included the particular codes being used in the identification task and their spatial and categorical relationship to each other. A second factor related to the number of codes present on the display. The particular response mapping used for the identification task served as a third factor, while the amount of experience with the task served as the fourth factor. The results found with these manipulations have been measured and explained, and therefore this objective has been met.

This chapter has shown that the presence of a non-redundant, irrelevant code in the target impacted the overall response latency as measured by total time per target. The nature of this effect was relatively subtle in that the impact on performance in identifying targets in the presence and absence of irrelevant codes differed depending on the particular code being identified (digits or letters) and was demonstrated only in the context of interaction effects between the various experimental manipulations. Further, and more to the point with regard to objective 1, the use of the WiTS response time partitioning methodology showed that the locus of the irrelevant code effect is clearly in input processing. No differences for the presence of irrelevant codes were found in the output time per target measure. Thus, this result illustrates the utility of partitioning response time into input and output components.

Objective 2 related to the demonstration and validation of the general approach to assessing display and response codes, and alternative response panel mappings as a function of task load in an identification task. The ability to detect and explain the findings of this experiment with regard to accuracy, total time per target, input time per target and output time per target de facto meets this objective. Even with the finding of unexpected significant effects, such as that for the four-way interaction found for input time in the analyses of blocks 4-10, it was possible to provide a meaningful interpretation of the results that suggested how the identification of certain target-task combinations using certain response mapping could affect input processing as a function of practice. Therefore, objective 2 has been met.

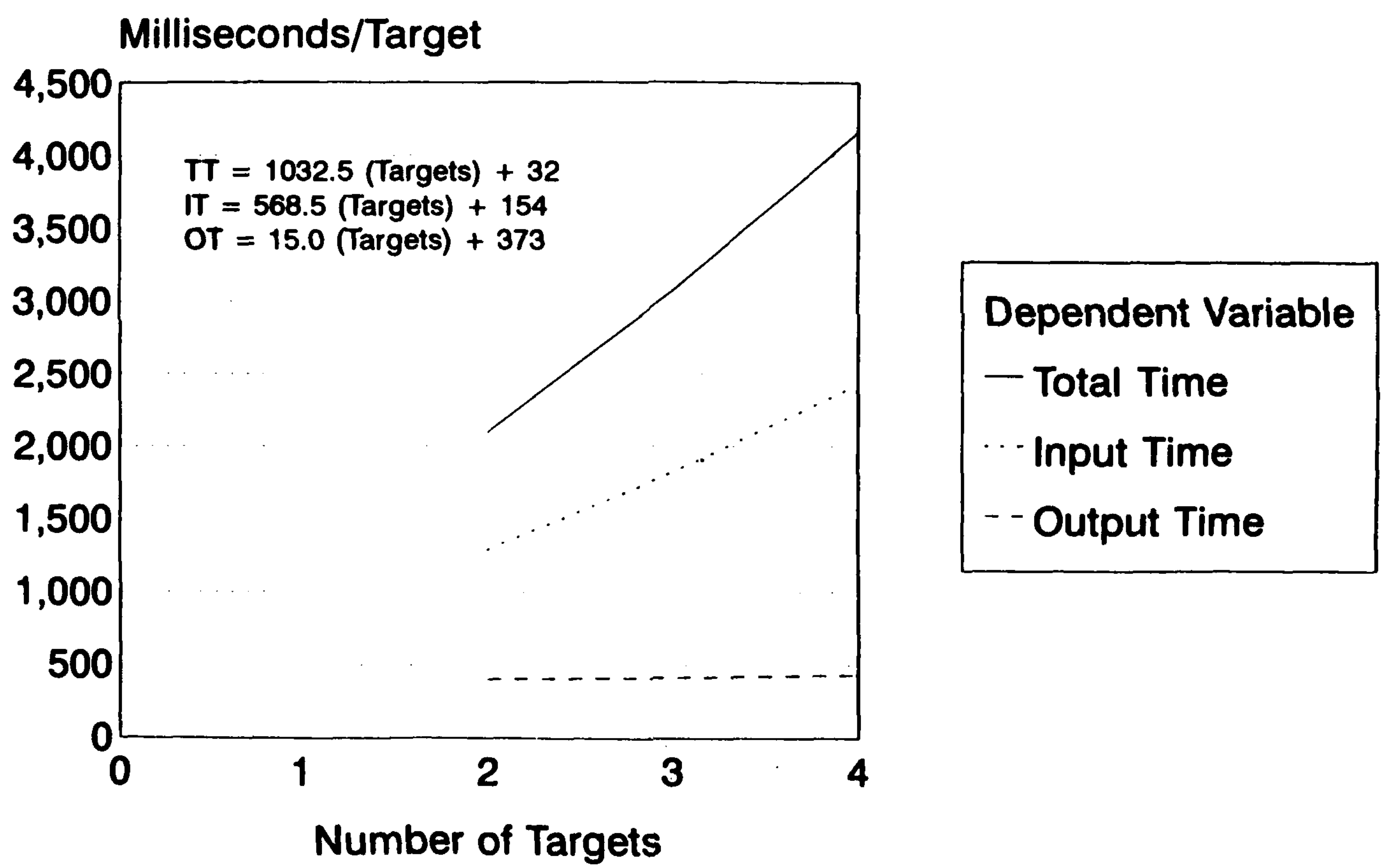
Objective three was the basis for the formulation of prediction 1. The finding of significant differences in accuracy of target identification, the rate of target identification as measured by total time per target, and input processing as measured by input time per target as a function of the presence of irrelevant codes in the identification of digits or letters demonstrates how this objective was met. Further, the results of this study indicate that the effects of identifying targets in the

presence of irrelevant codes is subtle, and dependent on the particular category of targets being identified. The identification of digits became both more accurate and slower in the presence of irrelevant letter codes. The identification of targets became slightly slower late in practice, when a large number of targets was being identified using the compound response mapping, suggesting that this condition created a fatigue effect after extensive time on task. Therefore, the understanding developed in Chapter 4 regarding the impact of identifying subsets of codes from different categories has been extended, and objective 3 has been met.

The fourth objective concerned the impact of alternative response mappings on performance in the identification of targets. While there were a number of effects for the response mapping in the study described in Chapter 4, the results for this study were less pervasive and even more subtle. Only two significant interactions were found for the response panel manipulation, and both of these were in the analyses for data from blocks 4-10. Response mapping effects were expected and found for the output time per target measure, because, on an intuitive basis it makes sense that the response mapping would affect output processing. The significant interaction for response mapping by target density which showed that the compound response mapping had a slower rate of output as the target density increased. These results suggest that there is a moderate cost in output processing for using the compound response mapping relative to that seen for the separate response mapping. Further, the input time four-way interaction for target-task, response mapping, target density and blocks in blocks 4-10 suggests that there may be a fatigue effect in the reading of information from a display and encoding it into memory which is contributed to by the particular response mapping used. Thus, this study demonstrated that the response mapping can affect both input and output processing, meeting objective 4.

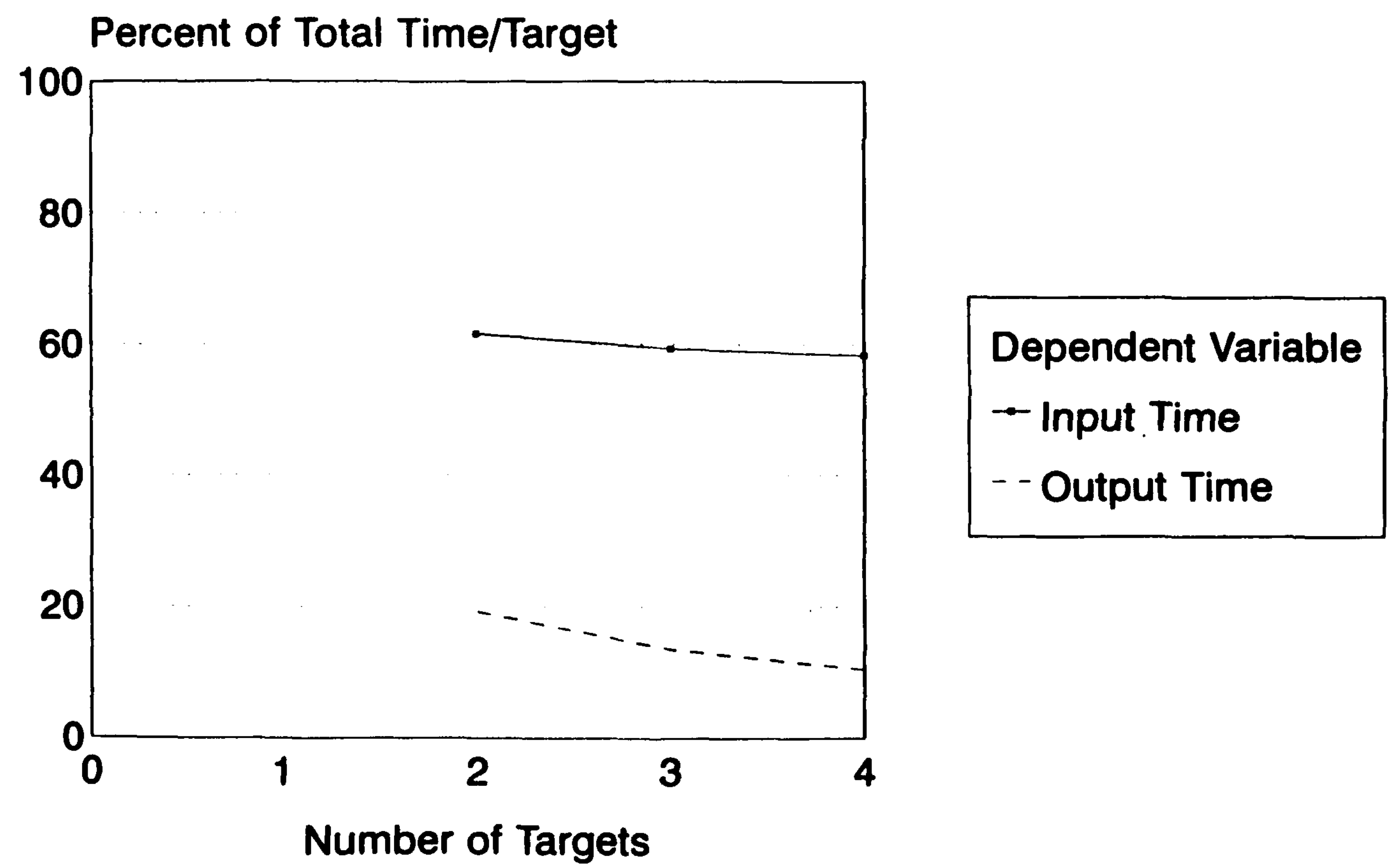
The utilization of rate measures in the form of total, input and output time per target in conjunction with the manipulation of target density allows the relative contribution of input and

Figure 5-10. Digits, Compound (Digits), Letters, Compound (Letters): Total, Input & Output Time by Number of Targets.



20 March 1992

Figure 5-11. Digits, Compound (Digits), Letters, Compound (Letters): Percent of Total Time accounted for by Input & Output Time



20 March 1992

output to overall processing to be assessed, as well as how the processing in input and output might be qualitatively different from each other. This objective was addressed in Chapter 4 through the use of a graph showing the relative change in total, input and output time per target as a function of the target density, and discussing the slopes and intercepts for the regressions of each dependent latency measure. This approach is replicated here in Figures 5-10 and 5-11. The first thing to be noted from these figures is that the results for the regressions shown in Figure 5-10 for the total, input and output time per target measures in identifying digits, compound (digits), letters and compound (letters) are essentially the same as those seen in Figure 4-10 for the identification of digits, letters, and separate (digit and letter targets in separate cells). Given the common data for half the conditions seen in Figure 5-10 with those in Figure 4-10, this is not surprising, but the fact that the slopes and intercepts are so similar despite the presence of some unique conditions does reaffirm the relative consistency of the relationship between total, input and output time. The findings of significant main and interaction effects for the target density for total, input and output time confirms the assertion that the identification of target contains significant information processing components. Further, because there were effects for both input and output time, it is concluded that both input and output involve significant processing components. Together, Figures 4-10 and 4-11 show that the bulk of processing in target identification takes place during input.

The interpretation of the slope of the regressions involving target density as a measure of rate of change in processing is supported by the intercepts seen in input and output time. Simple reaction times, i.e. response latencies where no discriminations are required in the display and no choices are required in the response, show a response time on the order of 200 msec. (Luce, 1984). This time also corresponds to the movement time between the rest position and a single response button (Fitts & Seeger, 1953; Fitts, 1954). If the regressions for input and output time per target are extrapolated for the condition where no targets are identified, the intercept should be close to that found in simple reaction time tasks. The empirical intercepts found in Figure 5-10 are in fact 154

msec. for input time, and 373 msec. for output time, which effectively validates this interpretation of the slopes and intercepts for these measures given the target density. Therefore, objective 6 has been met, the results provide empirical support for the assertion that input and output time per target are essentially measures of input and output processing.

Applications & Lessons Learned

One goal in this study was to provide results that would be meaningful to engineering, as well as theoretical applications. Therefore, this study will be summarized in the form of identifying prospective principles and guidelines in terms of both general methodological issues, and specific recommendations with regard to the effects of relevant and irrelevant codes.

1. The presence of irrelevant (noise) codes which from a category that is never relevant, i.e. symbols that are from a distinct category from that of the target codes depends on the particular category of code being identified. The effect of having irrelevant codes present when codes from the relevant category are processed more quickly and less accurately than they could be will be to slow down the rate that the codes are input and increase the accuracy with which they are processed. It may also be the case that the presence of irrelevant codes in a display and more complex response mappings may interact to cause a more rapid onset of fatigue, and therefore, with an extended time on task, the noise codes contribute to slower identification and reduced accuracy. Given these findings, it was concluded that while noise codes do affect processing, the effects may be very subtle. Further study of the effects of irrelevant codes is certainly warranted given the results in this study.

2. The results showed that when the relevant codes are digits, and the irrelevant codes are letters in an identification task, the effect of the noise (letter) codes is to increase the accuracy of the identification, and decrease the rate of identification. The change in accuracy was seen across all blocks of practice, while the slower rate of identification for digits in the presence of noise letters was seen only later in practice. When the task was

demanding, i.e. there were a large number of targets to be identified, the relevant codes were letters, and the noise codes were digits, and the responses were made with the compound response mapping, the rate of identification was significantly slower than it was with the other target-task-response mapping conditions.

3. The results suggest that the compound response mapping, and a high target density contribute to a fatigue effect in input, particularly with the identification of letter codes. This supports the assertion that response mapping and target density make the identification task more complex and cognitively demanding.

4. It appears that there are three primary effects associated with the presence of noise codes in a display. First, accuracy of identification may be increased for certain very rapidly identified codes, e.g. digits. Second, the rate of input is slowed down, probably because of the costs of filtering out the irrelevant codes. When the codes are from an irrelevant code category and are affected by the presence of noise codes (e.g. digits in the presence of noise letters), it appears that the irrelevant codes are processed, however because the increase is not comparable to the increase associated with additional relevant codes, it is concluded that the input processing associated with the noise codes is qualitatively different from that seen with the relevant codes. Second, the presence of noise codes may cause an increase in the rate of output, e.g. for the identification of letters in the presence of digits. This increase is attributed to an increase in the level of arousal (e.g. Grice & Gwynne, 1987) which effectively increases the rate of processing.

5. This study confirms the finding from Chapter 4; that digits are read from the display and encoded into memory faster than are letters on a per code basis. In fact, the difference between digits and letters was even more distinct in this study than it was in Chapter 4

because there was a significant main effect found for the comparison of input times for the digits conditions and letter conditions.

6. Consistent with the previous study, it can be concluded that the response mapping affects the way information is read from the display and encoded into memory. However, the effect of response mapping in this study was very subtle as it was found for only one of the noise target-task conditions (letters), with a high target density, and after a substantial period of time-on-task. Thus, with a complex and difficult task where fatigue may be contributing to the effect, the complexity of the response mapping should be considered during design whenever fatigue is an issue.

7. As with the previous study, the more codes that are presented to be identified, the slower will be the rate at which the codes processed. The effect is pervasive and affects overall, input and output processing.

8. Again, Teichner's theoretical distinction between input and output appears to be justified by the empirical results.

(This page intentionally left blank.)

CHAPTER 6 - Identification of Single versus Multiple Codes from Multiple Code Targets.

This chapter summarizes the results from the third in a series of studies examining the effects of display and response codes in an identification task. Chapter 4 describes the first of these studies, and examines the performance seen from identifying targets consisting of a single alphanumeric code. The results of that study showed that: 1) subsets of digits codes were processed differently from subsets of letter codes as measured by identification accuracy, overall response latency, input time and output time; and 2) that the identification of a subset of codes consisting of both digits and letters caused performance to be comparable to that of the least accurate and slowest identified of the component code categories as measured by identification accuracy, total time, and input time, but generated worse performance than that seen with either of the component categories as measured by output time.

Chapter 5 described the second study in the series and continued to examine the effects of display and response codes on information processing in an identification task. The tasks used in that study were comparable to the identification of single code categories seen in the first study, however the targets used were more complex because each target consisted of both a digit and a letter code. However, while subjects saw targets consisting of two codes from two different categories, (i.e. digits and letters), they were instructed to identify only one of the codes in each of the targets, (i.e. digits or letters). The results from Chapter 5 demonstrated several subtle effects. First, the presence of the irrelevant target code caused performance accuracy to improve for the identification of digits. This improvement in accuracy came with a slight cost in terms of the rate of

target identification, as became evident in those conditions where there were larger numbers of targets to be identified. The locus of the effect of the irrelevant target code was shown to be in input processing, as defined by Teichner's processing model and the Within-Task Subtractive (WiTS) response time partitioning methodology. There was an additional effect found for the presence of irrelevant codes in input time per target, which was found late in practice. This effect showed that the identification of letters using a relatively high compound target density and the compound response mapping led to slightly worse performance after approximately 270 trials than that seen with the identification of letters from single (letter) targets or the identification of digits from single or compound targets after the same number of trials. Thus, the presence of the irrelevant target codes apparently contributed to a fatigue effect late in practice.

The objectives of this study are consistent with those found in Chapters 4 and 5, and seek to extend them to the case where targets with multiple relevant codes are being identified. Specifically, the objectives are to:

1. Demonstrate the utility of the Within-Task Subtractive method of partitioning response time in terms of a) assessing performance in an identification task, and b) demonstrating the theoretical and practical implications of particular information codes and code arrangements have on information processing.

2. Assess the relative performance in terms of overall, input and output processing for codes which are integrated into single targets versus when the codes are in independent targets.

3. Assess the relative impact of alternative response mappings on input and output processing.

The studies reported in Chapters 4 and 5 describe a variety of effects for the arrangement of codes on the response panel. These effects were found to be fairly subtle in that there were no main effects for the response mapping, but instead appeared in the form of a variety of interaction effects. Further, there were effects seen in both input and output processing, demonstrating that the output side of the identification task was having an impact on the way subjects read information from a display and encoded it into memory.

The study described in this chapter will continue to assess the impact of display and response codes on information processing in an identification task. However, the focus in this chapter will be on the identification of codes in complex targets, i.e. the identification of both the digit and letter codes presented in a single, compound target. Given the significant effects found in the earlier chapter for comparing single targets from multiple code categories, the separate target-task condition will be used as the control condition for this comparison.

In overview, the results for the first two studies clearly show that: 1) the particular codes used as targets can and do affect input and output processing; 2) the presence of codes from two or more categories change performance relative to identifying codes from a single category, 3) the presence of codes in a single target change performance relative to when those codes are not present, and the effects seen will depend in part on the particular codes used; and 4) the particular response panel used can affect how targets are identified in terms of both how targets are read from a display and encoded into memory, and taken from memory and translated to a response. All these results were obtained when the identification task required the identification of a single code from the targets used. This study will now assess the identification of targets with multiple, relevant, code attributes.

Targets in complex visual displays often are designed to encode several types of information within the same target, or what many times is an icon or symbol. This is done in a variety of ways. One common mechanism for encoding more information into a single target is through the use of multiple attributes as codes, e.g. shape, size and/or and color. This approach is common in iconic formats such as those used to show system status, or those seen in object oriented interfaces (such as that seen in the Apple Macintosh computer, or the Microsoft Windows operating system; e.g. Wickens, 1980; Shneiderman, 1987; Brown, 1988). A second approach to encoding more information is through the use of a variety of alphanumeric labels, each of which references a different piece of information about the proximal target. This is an approach frequently used in tactical displays in aircraft, and air-traffic controller displays, (e.g. Van Cott & Kinkade, 1972; MIL-STD-1473C,1983; Andre & Wickens, 1988). This latter approach fits in conveniently with the particular codes and tasks described in the earlier chapters of this report, and will therefore be the basis of this study.

The question posed by this study is: How does the identification of multiple code targets compare to the identification of single code targets as measured by accuracy, overall response time per target, input time per target and output time per target? The question will be answered, at least in part, by comparing the compound and separate target-task conditions. These conditions are fully described in Chapter 3. The compound target-task condition presents subjects with a single target composed of a digit and a letter code and requires that the subject identify both codes. The separate target-task condition presents subjects with both digit and letter codes. However, the subject responds to a single digit <u>or</u> letter code. Because it was shown in Chapter 4 that the performance seen in identifying codes from two categories is different from that in identifying targets from single code categories, the separate target condition is clearly the best choice as a comparison condition for this study.

Before consideration is given to the possible outcomes of this study, and the potential theoretical implications of those results, it is appropriate to revisit the dependent measures in the context of the two target-task conditions used in this study. It should be readily apparent to the reader that if the target density is kept constant, and the compound target-task condition has twice as many codes per target than the separate target-task condition (all of which must be identified), then, logically, twice as many responses are required for the compound targets. As a result, there are twice as many opportunities for making errors in identifying the codes in the compound targets and the basic mechanics of responding should also make the response time take twice as long. This obviously complicates the formulation of experiment predictions, and the interpretation of the results. None the less, some predictions are possible with regard to the rate of identification measures if they are adjusted to take into account the number of codes being identified rather than the number of targets, as was done in the previous chapters. In effect, this means that for the compound and separate target-task conditions to be considered equivalent, the rate of target identification for the compound conditions should be twice that seen for the separate conditions for the same number of targets. This logic applies equally well to the total, input and output time per target measures.

If the codes are being processed identically for the separate and compound target-task conditions, then it can be intuitively expected that the total, input and output time per target measures for the compound target-task conditions would be twice those for the separate target-task conditions. However, there is one additional factor to be taken into account in generating a prediction for the total time per target and input time per target measures. This factor relates to the reading of the target codes from the compound targets, and their close proximity to each other. Both the codes read from the compound targets may be obtained in a single visual dwell[12], i.e.

[12]A dwell refers to those movements of the eye associated with the reading of information from a visual display. Harris, Glover & Spady (1986), and Morrison, (1988) note that while there are movements associated with the reading of information from a target in a display, they are relatively

there is no need to move the eye and fixate on the second target because both codes are in a single target, and that target falls entirely within the fovea of the eye. Therefore, it can be expected that there will be a net savings in the rate of reading codes from the compound targets relative to the time required to read a comparable number of codes from the separate targets. Further, because the movement time between dwells is fairly constant and not affected by the amount of information in the display (Harris, Glover & Spady, 1986; Tole, Stephens, Vivadou, Ephrath & Young, 1983), this saving should be relatively constant regardless of the number of targets actually being fixated. Therefore, in summary, it can be expected that the total and input time per target for the compound target-task conditions should be slightly faster than twice that for the separate target conditions, and the advantage will be constant regardless of the target density.

DESIGN

Figure 6-1 shows that four factors are manipulated for this study in a split-plot factorial design. The target-task type and response mapping are employed as between-subjects factors, and target density and blocks of practice are used as within-subjects factors. There were 10 subjects in each level of the between-subjects factors so that this experiment represents the data from 40 subjects. It should be noted that this study uses two between-subject conditions that were analyzed as part of Chapter 4 so that 20 of these subjects define the same data set used in that chapter. Data for two dependent variables were collected during the experiment, these being percent correct over all trials for a given condition within each block, and the response time for each response within a

---

small and short in duration. Therefore, they provide data to support the argument that the pattern of visual scanning around a target with information processing. By subtracting the times associated with larger movements, e.g. the time associated with saccades between dwells, (100-300 msec.; Young & Sheena, 1975), it is theoretically possible to calculate the exact amount of time spent obtaining information from a target. (See also Tole, et al., 1983).

Figure 6-1. Experimental Design for the Separate-Compound Comparison.

Between Factors		Within Factors			
		Number of Targets:	2	3	4
Target -Task Type	Response Mapping	Blocks:	1-10	1-10	1-10
Separate	Separate				
	Compound				
Compound	Separate				
	Compound				

trial. From the response time data, total response time per target, input time per target, and output time per target is calculated using the WiTS methodology described in Chapter 2. Finally, the average total time per target, input time per target and output time per target are calculated, and these are used as the basis for statistical analysis of performance for each condition within a block of practice along with percent correct.

There are two levels of the target-task manipulation. The separate condition refers to digits and letters being used as targets, with one code in each cell. The compound target-task condition refers to targets that consist of a digit and a letter. Subjects are instructed to identify all the digits and letters presented on a display during each trial for both target-task conditions. The digits used are selected from the set: 1, 2, 3, 4, 5, 6, 7 and 8. The letters used are selected from the set: A, B, C, D, E, F, G and H. Targets were randomly assigned to two, three or four cells in the 16-cell display matrix. The number of cells with targets in them was determined by the number of targets to be identified, (or code target density), therefore there were three levels target density. There were two levels of response mapping. The separate response mapping had a single digit or letter code associated with each of 16 response buttons. The compound response mapping had a digit and letter code associated with each of 8 response buttons. Additional information regarding the targets used, the counter-balancing of codes within targets, the response mappings, and the displays and apparatus used may be found in Chapter 3.

With the experimental design and the rationale given above, it is now possible to formulate some empirical predictions for the identification of codes in single and compound targets.

1. If the latency performance seen from the compound target-task conditions is approximately twice that seen for the separate target-task conditions as indicated by the rate of change in time per target (as measured by total time per target and input time per target), then the

overall and input processing of the compound target-task conditions is the same as that seen in the single code per target conditions.

2. If there is a significant interaction effect involving the response mapping and the target density, then it can be concluded that the response mapping affects the way information is processed in an identification task. Such a result would be consistent with the results of Chapters 4 and 5. Further, if such an effect is found in input time per target, then the response mapping affects the way information is read from the display and encoded into memory. If an interaction effect with response mapping and target density is found in output time per target, then the response mapping affects the way information is taken from memory and translated to a response.

RESULTS

The basic comparison of the separate and compound targets is performed through a series of multi-variate analysis of variance (MANOVA) procedures. All MANOVAs were performed using the Complete Statistical Software (CSS: Statistica) analysis package for MS-DOS computers (Statsoft, 1991). Post-hoc comparisons for significant effects were performed using the Newman-Keuls procedure (Kirk, 1982; Statsoft, 1991) included as part of this statistical software[13]. A separate MANOVA was performed for each of the dependent variables: Percent Correct, Total Time per target, Input Time per target, and Output Time per target. The results of these analyses are summarized in Table 6-1 and are described in detail below. Based on the results for practice described in Chapters 4 and 5, and the finding of significant learning effects during the first three blocks, additional analyses were performed for just blocks 1-3 and again for blocks 4-10. These analyses are summarized in Table 6-2 and Table 6-3. The results for all the dependent variables will now be discussed in turn.

Percent Correct. Four significant effects were found in the analysis for the percent correct data over all blocks. There was a significant main effect for the target-task comparison where the separate targets were identified more accurately than the compound targets (96.1% versus 82.1% for the separate and compound target-task conditions respectively, (F=49.3, (1,26), $p < .01$). There was also a significant target density main effect where accuracy of target identification decreased as the density increased (97.0%, 91.4% and 78.8% for the 2, 3 and 4 target conditions, F=71.9, (2,52),

[13]It should be noted that there were a significant number of missing cells in the analyses involving the compound target-task condition due to subjects failing to accurately identify any targets in one of the within-cells conditions. This missing data required procedures to be used in the analyses that adjust for an unbalanced design. As part of its procedure, CSS:Statistica drops subjects with an excessive amount of missing data so that the resulting matrices are not singular. The means reported in this Chapter will reflect the means used by CSS:Statistica after adjusting for unbalanced design.

TABLE 6-1. Summary of MANOVA results for Separate, Compound.[48] [49] [50]

EFFECT:	% CORRECT:	TOTAL TIME:	INPUT TIME:	OUTPUT TIME:
Condition (C)	F=49.3,(1,26) p < .01	F=152,(1,26) p < .01	F=111,(1,26) p < .01	F=2.79,(1,26) p = .107
Response (R)	F=0.73,(1,26) p = .400	F=3.39,(1,26) p = .077	F=7.77,(1,26) p < .01	F=0.15,(1,26) p = .706
C_R	F=0.27,(1,26) p = .611	F=4.39,(1,26) p < .05	F=5.75,(1,26) p < .05	F=1.24,(1,26) p = .276
Targets (T)	F=71.9,(2,52) p < .01	F=451,(2,52) p < .01	F=330,(2,52) p < .01	F=14.0,(2,52) p < .01
C_T	F=54.2,(2,52) p < .01	F=88.1,(2,52) p < .01	F=90.9,(2,52) p < .01	F=0.92,(2,52) p = .406
R_T	F=0.73,(2,52) p = .487	F=0.70,(2,52) p = .500	F=3.27,(2,52) p < .05	F=4.72,(2,52) p < .05
C_R_T	F=0.08,(2,52) p = .920	F=3.18,(2,52) p < .05	F=2.59,(6,52) p = .085	F=3.17,(2,52) p = .050
Block (B)	F=0.41,(9,234) p = .927	F=9.82,(9,234) p < .01	F=2.15,(9,234) p < .05	F=12.36,(9,234) p < .01
C_B	F=0.29,(9,234) p = .978	F=1.49,(9,234) p = .151	F=5.75,(9,234) p < .05	F=1.09,(9,234) p = .373

[48]Condition (C) refers to the target-task conditions used in this analysis. Response (R) refers to the response panel mapping effect. Targets (T) refers to the number of targets being identified. Block (B) refers to the number of blocks of practice. Interaction effects are denoted by the abbreviation for the effects separated by an underscore, e.g. C_R indicates the Contrast by Response mapping interaction.

[49] Analysis uses {Separate-Both-Separate, Separate-Both-Compound, Compound-Both-Separate, Compound-Both-Compound} as groups.

[50]Table based on analyses of- March 31, 1992

R_B	F=0.68,(9,234) p = .731	F=1.24,(9,234) p = .271	F=0.89,(9,234) p = .533	F=0.72,(9,234) p = .688
C_R_B	F=1.27,(9,234) p = .256	F=0.78,(9,234) p = .636	F=2.14,(9,234) p < .05	F=0.29,(9,234) p = .977
T_B	F=0.74,(18,468) p = .770	F=1.93,(18,468) p < .05	F=0.75,(18,468) p = .756	F=0.99,(18,468) p = .471
C_T_B	F=1.44,(18,468) p = .108	F=1.62,(18,468) p = .052	F=1.08,(18,468) p = .372	F=1.23,(18,468) p = .229
R_T_B	F=2.06,(18,468) p < .01	F=1.94,(18,468) p < .05	F=1.07,(18,468) p = .384	F=0.92,(18,468) p = .549
C_R_T_B	F=1.47,(18,468) p = .094	F=1.68,(18,468) p < .05	F=1.60,(18,468) p = .056	F=0.50,(18,468) p = .959

TABLE 6-2. Summary of MANOVA results for Separate,Compound: Blocks 1-3 of practice.[51] [52] [53]

EFFECT:	% CORRECT:	TOTAL TIME:	INPUT TIME:	OUTPUT TIME:
Condition (C)	F=38.4,(1,28) $p < .01$	F=208,(1,28) $p < .01$	F=123,(1,28) $p < .01$	F=6.70,(1,28) $p < .05$
Response (R)	F=0.59,(1,28) $p = .451$	F=0.95,(1,28) $p = .337$	F=2.63,(1,28) $p = .116$	F=0.03,(1,28) $p = .853$
C_R	F=3.31,(1,28) $p = .080$	F=0.50,(1,28) $p = .485$	F=0.01,(1,28) $p = .980$	F=1.18,(1,28) $p = .288$
Targets (T)	F=42.2,(2,56) $p < .01$	F=354,(2,56) $p < .01$	F=224,(2,56) $p < .01$	F=19.1,(2,56) $p < .01$
C_T	F=38.5,(2,56) $p < .01$	F=74.4,(2,56) $p < .01$	F=76.5,(2,56) $p < .01$	F=3.69,(2,56) $p < .05$
R_T	F=2.40,(2,56) $p = .100$	F=0.23,(2,56) $p = .794$	F=0.04,(2,56) $p = .957$	F=3.01,(2,56) $p = .057$
C_R_T	F=0.35,(2,56) $p = .706$	F=0.90,(2,56) $p = .410$	F=0.36,(2,56) $p = .702$	F=3.29,(2,56) $p < .05$
Block (B)	F=0.35,(2,56) $p = .708$	F=8.18,(2,56) $p < .01$	F=0.51,(2,56) $p = .604$	F=29.3,(2,56) $p < .01$
C_B	F=1.26,(2,56) $p = .292$	F=1.73,(2,56) $p = .186$	F=4.06,(2,56) $p < .05$	F=2.56,(2,56) $p = .087$

---

[51]Condition (C) refers to the target-task conditions used in this analysis. Response (R) refers to the response panel mapping effect. Targets (T) refers to the number of targets being identified. Block (B) refers to the number of blocks of practice. Interaction effects are denoted by the abbreviation for the effects separated by an underscore, e.g. C_R indicates the Contrast by Response mapping interaction.

[52] Analysis uses {Separate-Both-Separate, Separate-Both-Compound, Compound-Both-Separate, Compound-Both-Compound} as groups.

[53]Table based on analyses of- March 31, 1992

R_B	$F=0.18,(2,56)$ $p = .836$	$F=4.59,(2,56)$ $p < .05$	$F=3.92,(2,56)$ $p < .05$	$F=1.82,(2,56)$ $p = .172$
C_R_B	$F=1.51,(2,56)$ $p = .229$	$F=1.50,(2,56)$ $p = .231$	$F=1.62,(2,56)$ $p = .207$	$F=0.40,(2,56)$ $p = .674$
T_B	$F=0.78,(4,112)$ $p = .543$	$F=0.99,(4,112)$ $p = .419$	$F=1.01,(4,112)$ $p = .405$	$F=0.81,(4,112)$ $p = .520$
C_T_B	$F=1.85,(4,112)$ $p = .125$	$F=1.18,(4,112)$ $p = .324$	$F=1.50,(4,112)$ $p = .208$	$F=0.70,(4,112)$ $p = .594$
R_T_B	$F=0.68,(4,112)$ $p = .609$	$F=2.35,(4,112)$ $p = .058$	$F=2.84,(4,112)$ $p < .05$	$F=0.54,(4,112)$ $p = .703$
C_R_T_B	$F=0.20,(4,112)$ $p = .938$	$F=1.64,(4,112)$ $p = .168$	$F=3.36,(4,112)$ $p < .05$	$F=0.12,(4,112)$ $p = .974$

TABLE 6-3. Summary of MANOVA results for Separate, Compound: Blocks 4-10 of practice.[54] [55] [56]

EFFECT:	% CORRECT:	TOTAL TIME:	INPUT TIME:	OUTPUT TIME:
Condition s (C)	F=42.6,(1,32) p < .01	F=190,(1,32) p < .01	F=184,(1,32) p < .01	F=5.74,(1,32) p < .05
Response (R)	F=0.28,(1,32) p = .868	F=0.58,(1,32) p = .451	F=1.93,(1,32) p = .175	F=0.01,(1,32) p = .935
C_R	F=0.01,(1,32) p = .998	F=1.55,(1,32) p = .222	F=2.52,(1,32) p = .122	F=0.46,(1,32) p = .502
Targets (T)	F=56.0,(2,64) p < .01	F=454,(2,64) p < .01	F=399,(2,64) p < .01	F=11.1,(2,64) p < .01
C_T	F=38.5,(2,64) p < .01	F=108,(2,64) p < .01	F=124,(2,64) p < .01	F=0.10,(2,64) p = .908
R_T	F=0.46,(2,64) p= .635	F=0.71,(2,64) p = .932	F=0.57,(2,64) p = .568	F=5.61,(2,64) p < .01
C_R_T	F=0.18,(2,64) p = .838	F=0.51,(2,64) p = .603	F=0.30,(6,64) p = .743	F=0.67,(2,64) p = .673
Block (B)	F=0.61,(6,192) p = .720	F=0.70,(6,192) p = .648	F=0.46,(6,192) p = .840	F=0.67,(6,192) p = .673

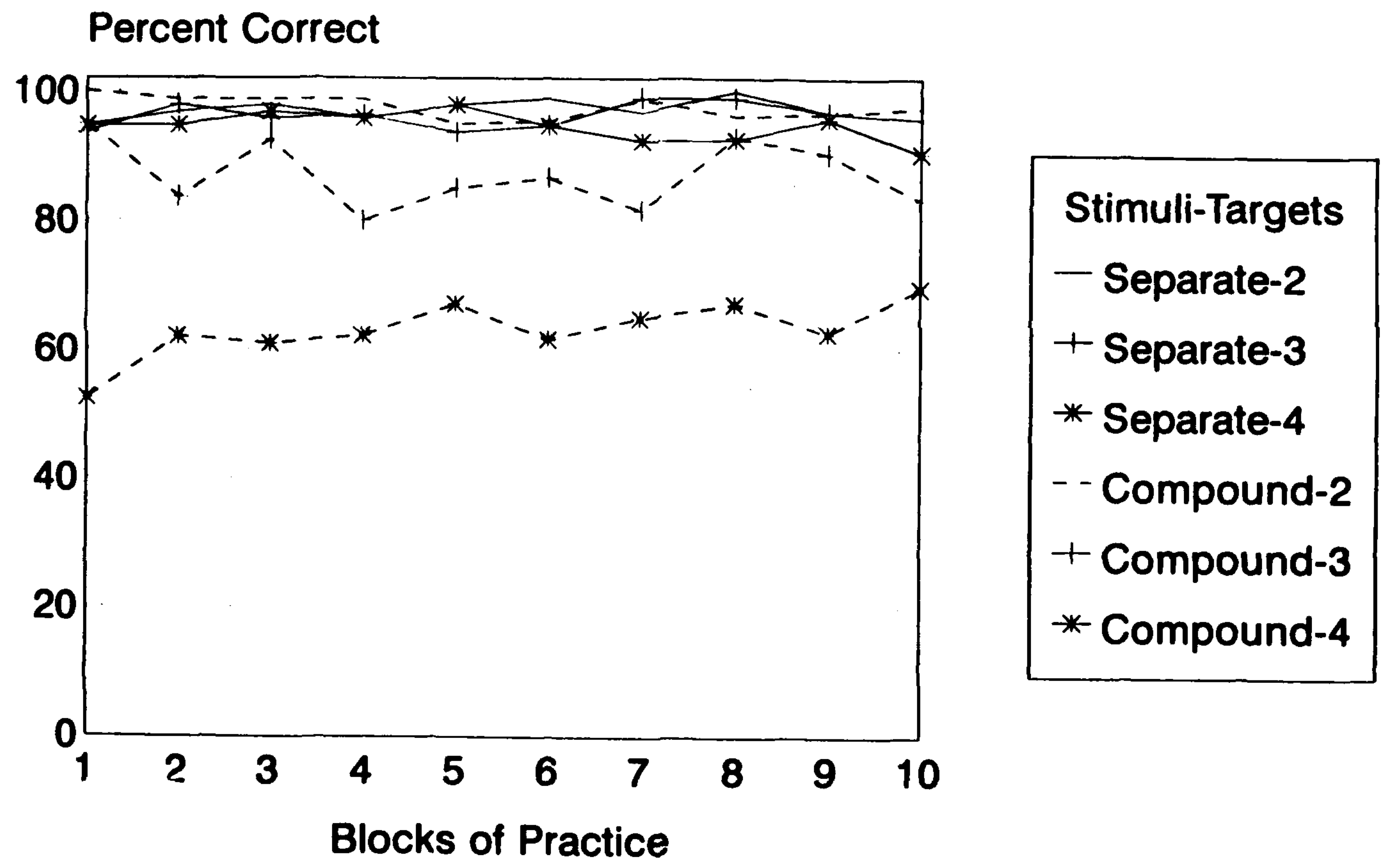
[54] Condition (C) refers to the target-task conditions used in this analysis. Response (R) refers to the response panel mapping effect. Targets (T) refers to the number of targets being identified. Block (B) refers to the number of blocks of practice. Interaction effects are denoted by the abbreviation for the effects separated by an underscore, e.g. C_R indicates the Condition by Response mapping interaction.

[55] Analysis uses {Separate-Both-Separate, Separate-Both-Compound, Compound-Both-Separate, Compound-Both-Compound} as groups.

[56] Table based on analyses of- March 31, 1992

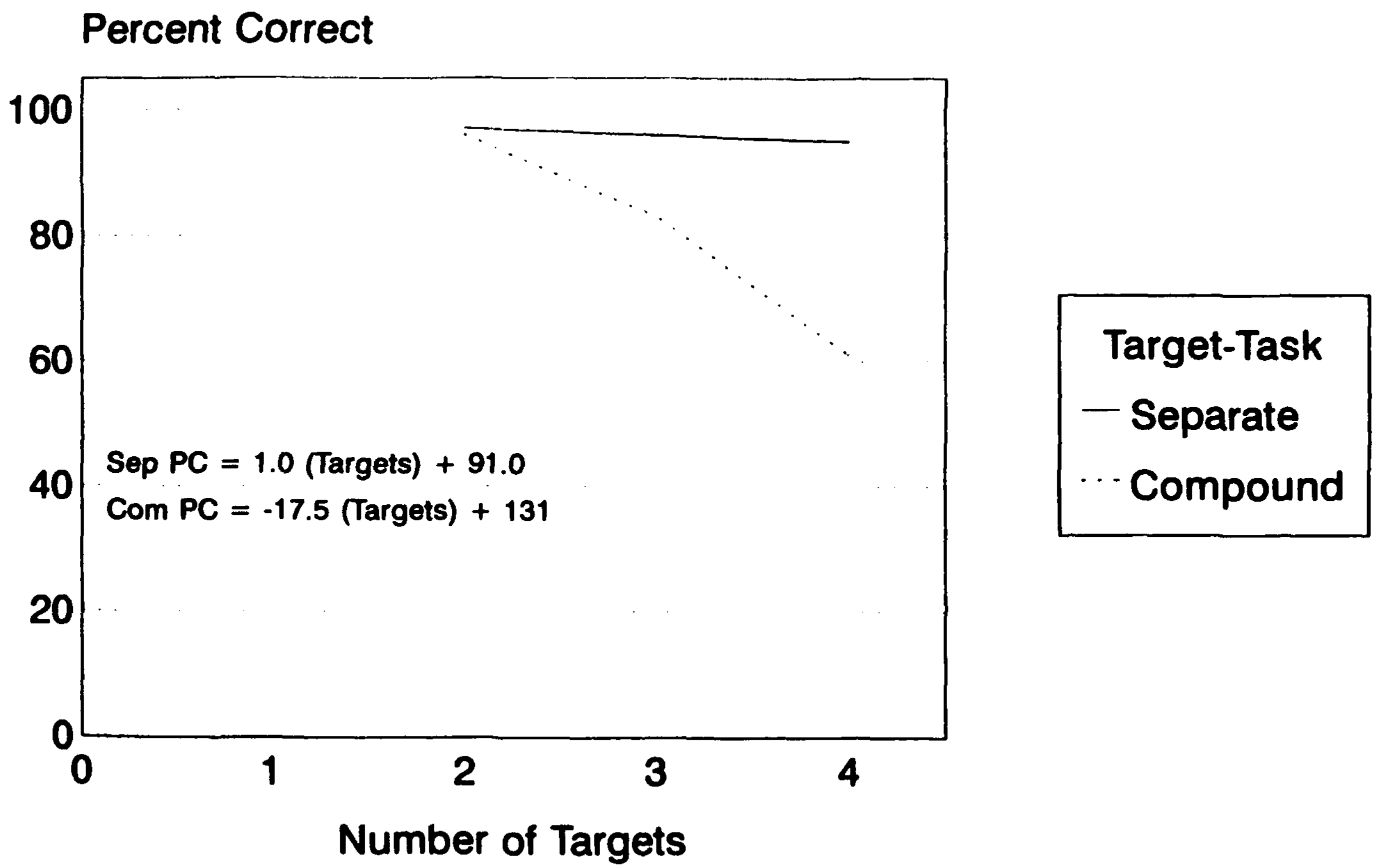
C_B	F=0.44,(6,192) p = .853	F=1.55,(6,192) p = .222	F=0.38,(6,192) p = .894	F=1.67,(6,192) p = .131
R_B	F=1.07,(6,192) p = .383	F=1.26,(6,192) p = .276	F=0.72,(6,192) p = .635	F=0.95,(6,192) p = .463
C_R_B	F=1.32,(6,192) p = .251	F=0.65,(6,192) p = .693	F=0.50,(6,192) p = .808	F=1.10,(6,192) p = .364
T_B	F=0.80,(12,384) p = .652	F=0.76,(12,384) p = .693	F=0.38,(12,384) p = .969	F=0.61,(12,384) p = .837
C_T_B	F=0.99,(12,384) p = .457	F=0.82,(12,384) p = .632	F=0.48,(12,384) p = .933	F=1.06,(12,384) p = .391
R_T_B	F=1.33,(12,384) p = .199	F=1.33,(12,384) p = .200	F=0.70,(12,384) p = .749	F=1.03,(12,384) p = .424
C_R_T_B	F=1.32,(12,384) p = .204	F=1.03,(12,384) p = .416	F=1.23,(12,384) p = .257	F=0.79,(12,384) p = .656

Figure 6-2. Separate, Compound:
Percent Correct



30 July 1992

Figure 6-3. Separate, Compound:
Percent Correct - Target-Task by Number of Targets Interaction.



1 April 1992

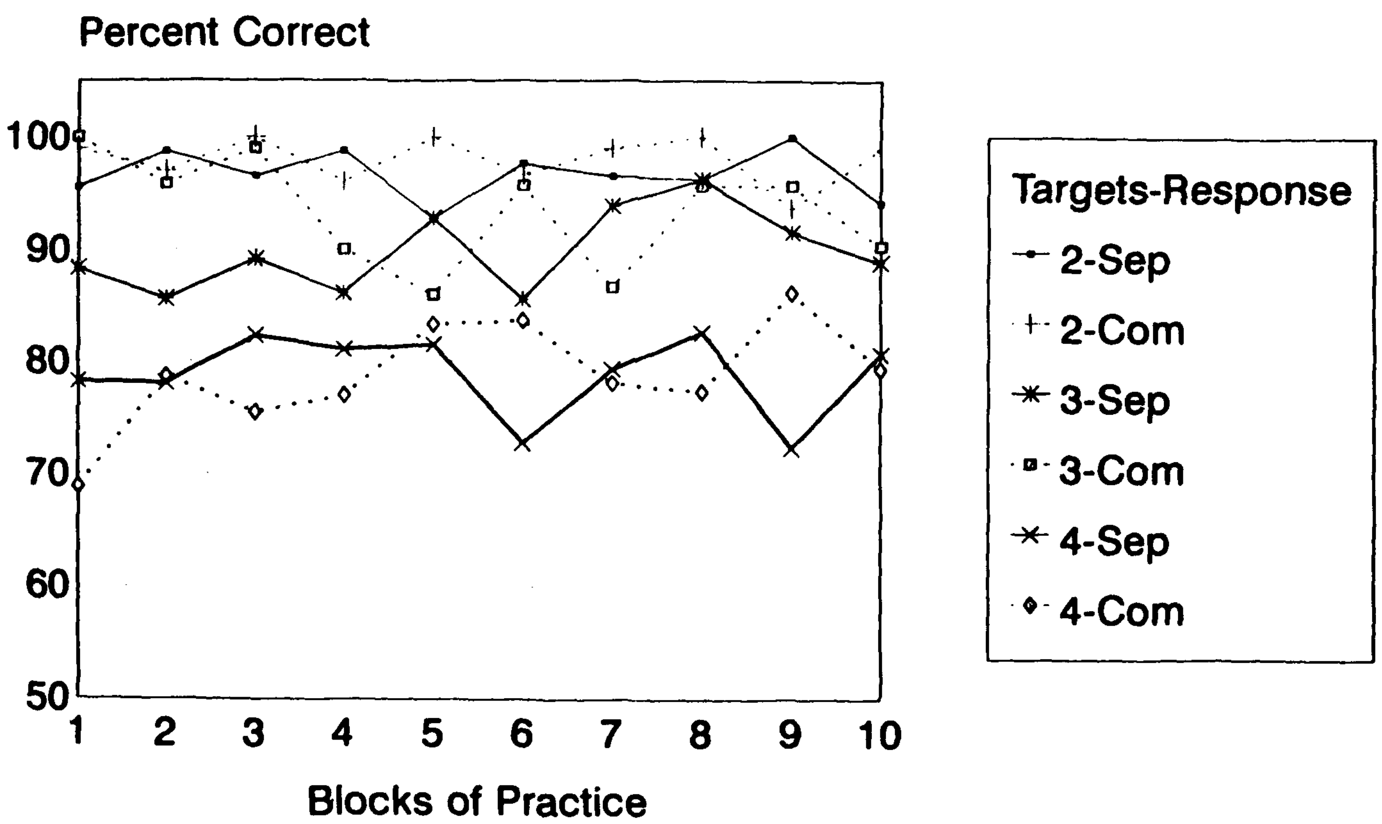
$p < .01$). These effects may be seen in Figure 6-2. The remaining effects for the analysis of percent correct data over all blocks involved interaction effects between the target-task conditions and target density ($\underline{F}=54.2$, (2,52), $p < .01$), and a three-way interaction for response mapping by target density by blocks ($\underline{F}=2.06$, (18,648), $p < .01$). The target-task by number of targets interaction, shown in Figure 6-3, was due to significant differences between the compound and separate target-task conditions when either three or four targets were to be identified. In effect, the accuracy for identifying the codes in the compound targets dropped at a rate of 17.5% for every additional target that was identified. The regressions for the functions shown in Figure 6-3 are:

$$\text{Percent Correct}_{\text{Separate}} = 1.0\ (\text{Number of Targets}) + 91.0\%;$$

$$\text{Percent Correct}_{\text{Compound}} = -17.5\ (\text{Number of Targets}) + 131.0\%.$$

The three-way interaction between response mapping by target density by blocks for the accuracy data was something of a surprise given the results found in Chapter 4 and 5. As may be seen from Figure 6-4, the effect was due to two significant factors which occurred early and late in practice. Overall, there was no significant difference between the separate and compound response mapping when two or three targets being identified. Early in practice, there were significant differences between the separate and compound response mappings in the first, third and fourth blocks. In these blocks, identification of four targets with the compound response mapping was significantly less accurate than with the separate response mapping. The significant effects late in practice occurred in both blocks 6 and 8, where the separate condition had significantly worse performance than the compound response mapping when four targets were being identified. Thus, when four targets were identified, the separate condition went from being significantly better in performance early in practice, to becoming (intermittently at least) significantly worse than the compound condition late in practice. There were no distinct performance differences as a function of practice when three targets were being identified.

Figure 6-4. Separate, Compound:
Percent Correct - Blocks 1-10 Interaction for
Response Mapping by Number of Targets by Blocks



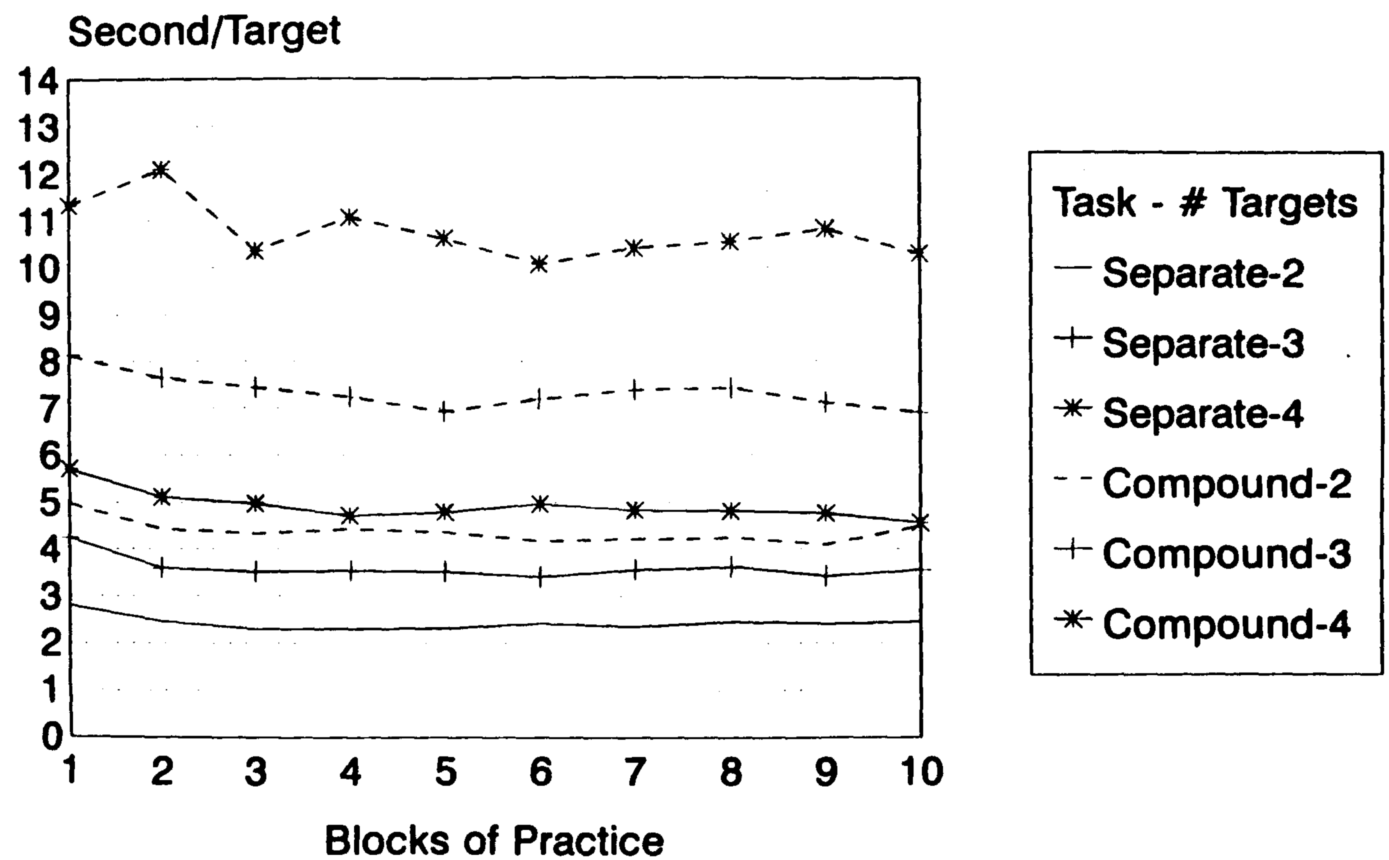
8 April 1992

The percent correct data from blocks 1-3 was consistent with that seen over all blocks. There were significant main effects for the separate-compound target-task comparison ($\underline{F}$=38.4, (1,28), p < .01; 95.8% and 78.1% correct for the separate and compound target-task conditions) and the target density ($\underline{F}$=42.2, (2,56) p < .01; 96.1%, 88.9%, and 75.9% for the 2, 3 and 4 target conditions). There was also a significant target-task by target density interaction ($\underline{F}$=38.5, (2,56), p < .01). Again, this interaction was significant because the compound target-task condition was identified significantly less accurately when four targets were being identified, while the conditions where two and three targets were being identified were not significantly different from each other.

The pattern of significant results for the percent correct data from blocks 4-10 was identical to that seen for blocks 1-4. There were two significant main effects; the separate versus compound target-task comparison was significant ($\underline{F}$=42.6, (1,32), p < .01), (96.0% for separate versus 82.1% for the compound targets). The target density effect was significant as well ($\underline{F}$=56.0, (2,64), p < .01), (97.0%, 91.4% and 78.8% for the 2, 3 and 4 target conditions). All levels of both factors were significantly different from each other. There was one significant interaction for the target-task comparison by target density, ($\underline{F}$=38.5, (2,64), p < .01). As with the overall analysis, this interaction was due to performance with the separate target-task condition being significantly less accurate when there were four targets to be identified, in both blocks 6 and 8 of practice relative to all other target-task and density conditions. Overall, there was no difference in performance when two or three targets were identified.

Total Time. Figure 6-5 illustrates the significant main effects for the total time per target data over blocks 1-10. There was a significant main effect for the target-task comparison, ($\underline{F}$=152, (1,26), p < .01), with the separate targets being identified faster than the compound targets, (3645 msec. per target versus 7479 msec. per target). There was also a main effect for the target density, ($\underline{F}$=451, (2,52), p < .01), where the 2, 3 and 4 targets conditions were all significantly different from each

Figure 6-5. Separate, Compound:
Total Time



other (3387, 5468 and 7831 msec. per target respectively). Finally, there was a significant main effect for blocks, ($\underline{F}$=9.82, (9,234), $p < .01$), where performance improved significantly over each of the first three blocks, (6350, 6095 and 5921 msec. per target for blocks 1, 2 and 3 versus and average of 5972 msec. per target over blocks 4-10).

In addition to the significant main effects for the total time per target measure over all blocks, there were a number of significant interaction effects. Two interactions involving the response mapping and total time are illustrated in Figure 6-6. The first significant interaction to be discussed is the three-way interaction between the separate-compound target-task comparison, response mapping and number of targets to be identified, ($\underline{F}$=3.18, (2,52), $p < .01$). The interaction is a product of significant differences between the compound target-task condition for the two response mappings when 4 targets were being identified. The separate response mapping was significantly slower overall than the compound response mapping when 3 or 4 targets were being identified. The separate target-task conditions were not significantly different from each other as a function of response mapping. As the target density increased, the total time per target for the compound target-task condition increased an average of 3204.5 msec. per target^2, which was a significantly faster increase than the 1239.5 msec. per target^2 for the separate target-task conditions[14]. The regressions for each of the target-task by response mappings as a function of the target density are[15]:

$$\text{Total Time}_{\text{Separate-Separate}} = 1141.0\ (\text{Targets}) + 201$$

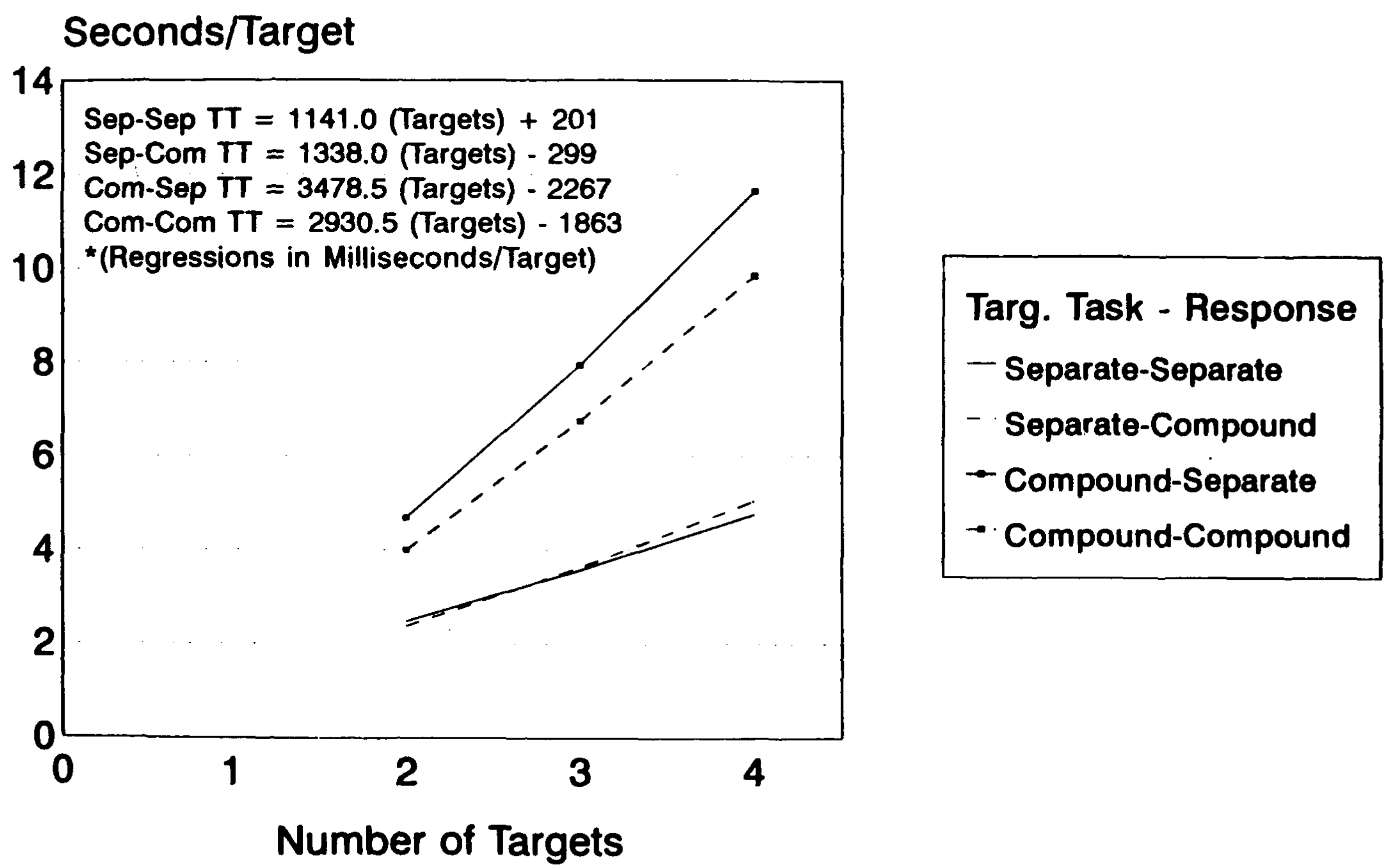
$$\text{Total Time}_{\text{Separate-Compound}} = 1338.0\ (\text{Targets}) - 299$$

$$\text{Total Time}_{\text{Compound-Separate}} = 3478.5\ (\text{Targets}) - 2267$$

[14]These rate of change measures were calculated based on averaging the slopes shown in Figure 6-6 for the two separate target-task conditions (1441, 1338 msec/target^2), and the two compound target-task conditions (3478.5 and 2930.5 msec/target^2).

[15]The subscripts in these equations denote the target-task and then the response panel mapping condition.

Figure 6-6. Separate, Compound: Total Time
Condition by Response Mapping by Number of Targets Interaction

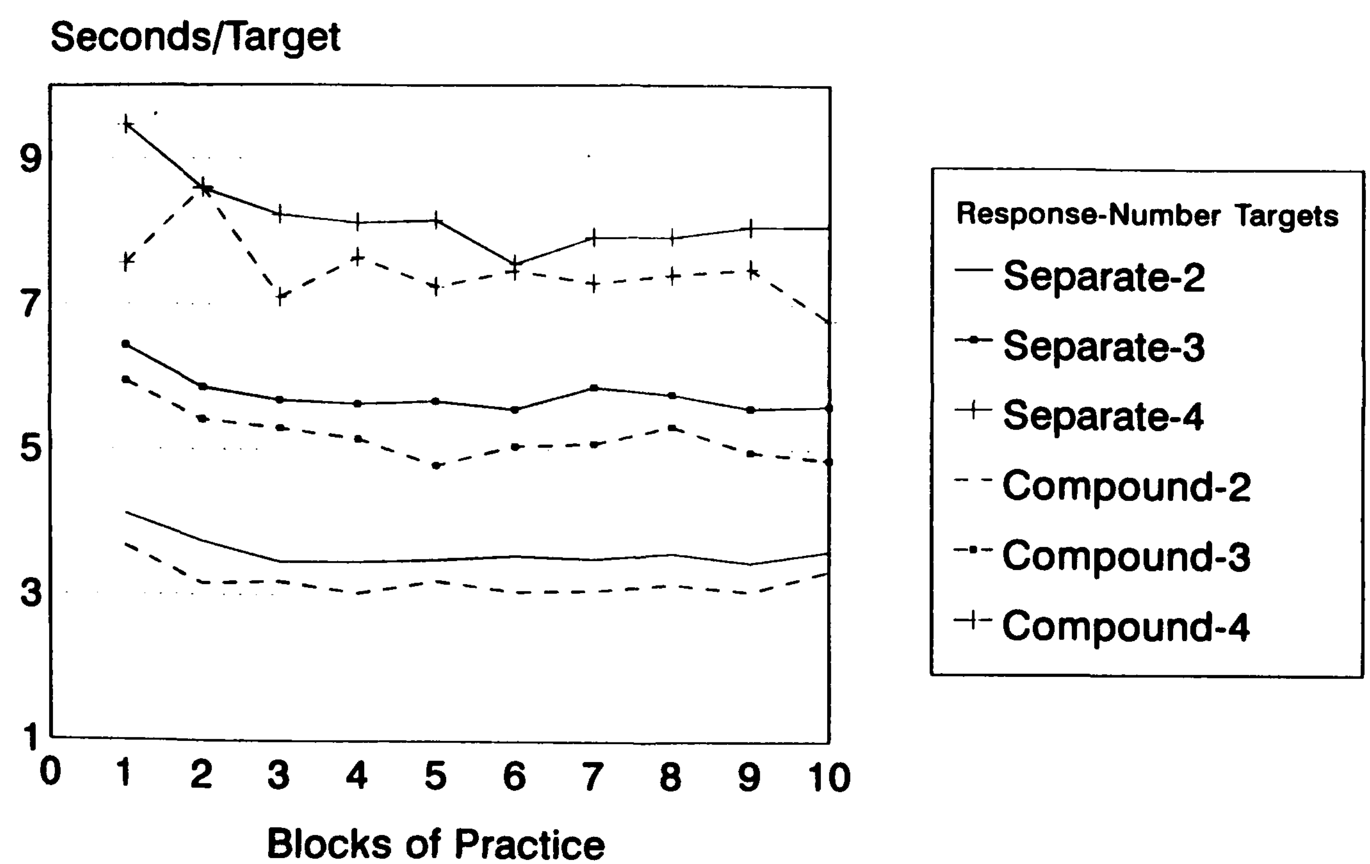


8 April 1992

$$\text{Total Time}_{\text{Compound-Compound}} = 2930.5\ (\text{Targets}) - 1863$$

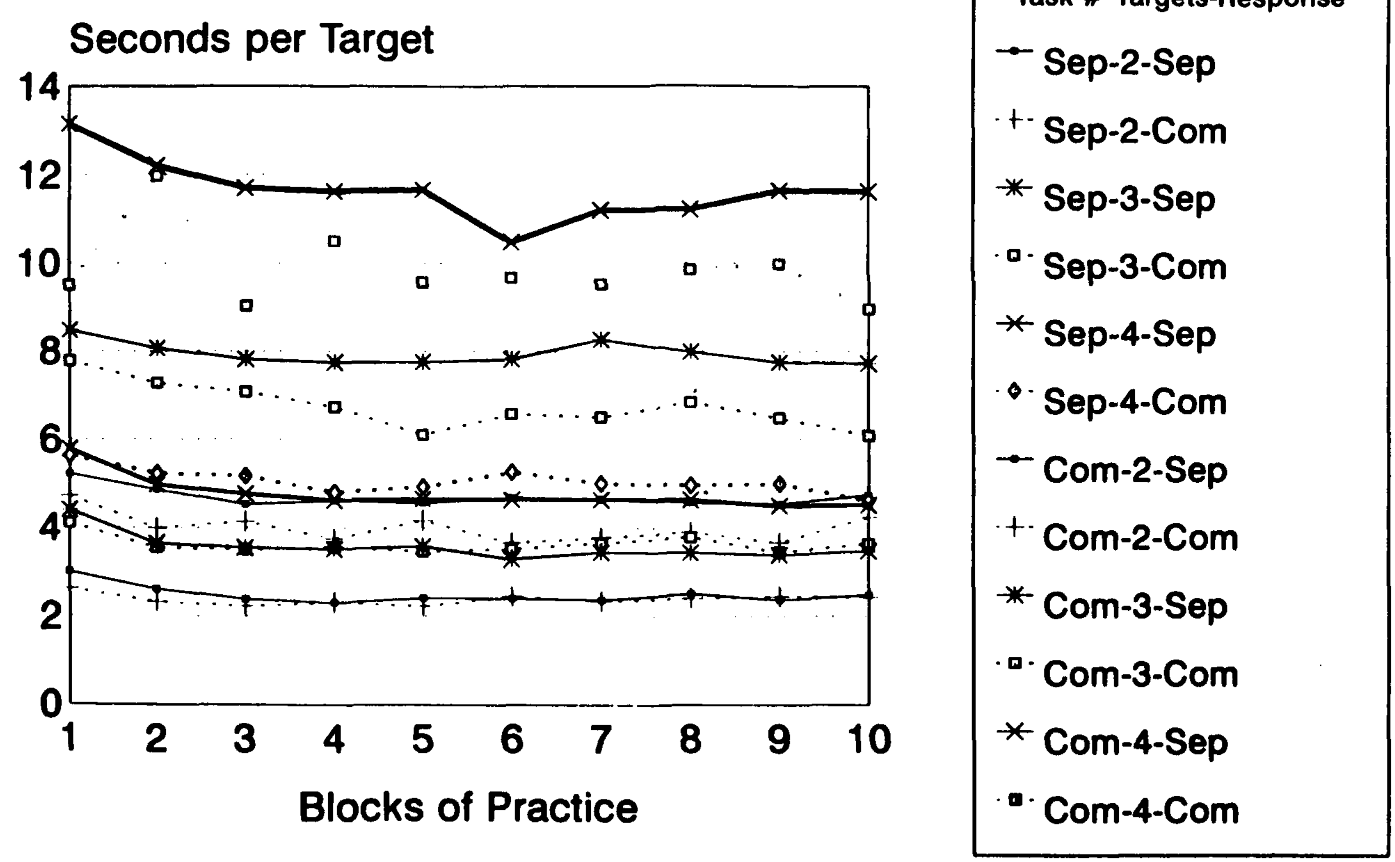
There were three interactions involving the number of blocks being identified. First, there was a two-way response mapping by blocks interaction (F=4.59, (2,56), $p < .05$) where the rate of identification with the separate response mapping was significantly slower than the compound response mapping in the first block of practice. The difference between the performance with the separate and compound response mappings was not significantly different from each of any of blocks 2-10 of practice. The net result of this effect is that there was less improvement in performance as measured by total time per target when the compound response mapping was used than when the separate response mapping was used for all but the first block of practice. There was a significant three-way response mapping by target density by blocks interaction effect for blocks 1-10 as well, (F=1.94, (18,468), $p < .05$). This interaction, also illustrated by Figure 6-7, reflects the performance in blocks 1 and 10 of practice being significantly faster for the identification of four targets when the compound response panel was used, while there were no significant differences between the response mappings in any blocks when two or three targets were being identified. Thus, the bulk of the difference in performance with practice for the separate and compound response mappings is due to the lack of improvement when four targets were being identified. This effect is further moderated by the presence of a significant four-way interaction for the separate-compound target-task conditions, response mapping, by number of targets, by blocks manipulations. From Figure 6-8 it may be seen that in block 1 of practice, identification of targets using the separate response mapping is significantly slower with the identification of compound targets, than it is with any of the other targets. In summary, it appears that the rate of target identification with the four compound target-task target when using the compound response mapping was significantly less stable than it was for any other target-task by number of targets by response mapping condition. The significant four-way interaction came about because this condition started by being significantly better than its comparable separate target-task condition with no experience on the task, and then worsened from

Figure 6-7. Separate, Compound: Total Time
Response Mapping by Number of Targets By Blocks Interaction



8 April 1992

Figure 6-8. Separate, Compound:
Total Time - Blocks 1-10 Interaction for
Contrast by Response Mapping by Number of Targets



30 July 1992

the first to second block of practice, before performance improved to its previous level of performance in block three. This was the primary factor in generating the significant two-, three- and four-way significant blocks effects which also involved the response mapping manipulation.

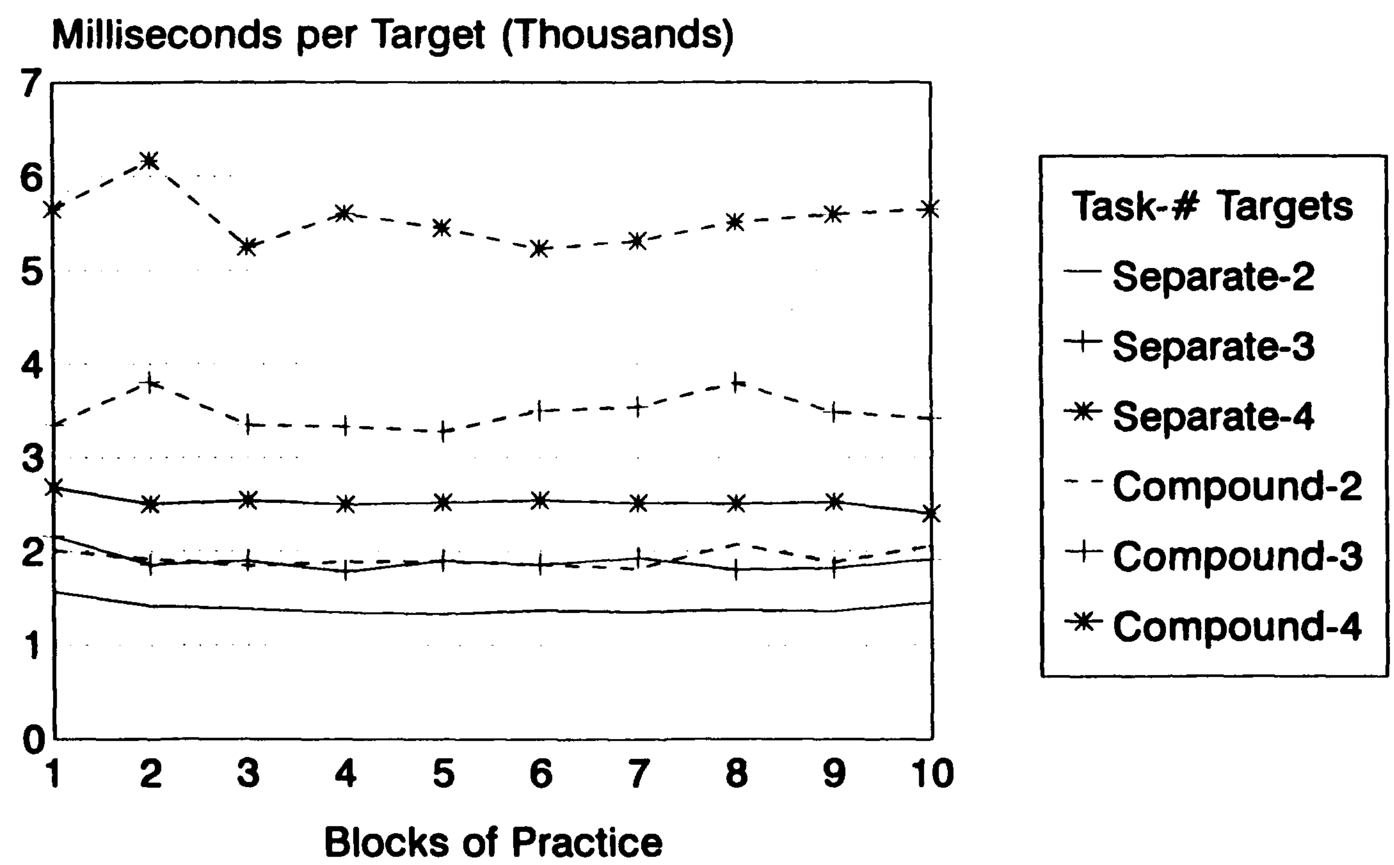
The unexpected blocks by response mapping effects were largely eliminated by partitioning the blocks manipulation into early and late practice. The only significant blocks interaction found in the analysis of total time per target for blocks 1-3 was for the two-way interaction of response mapping and blocks ($\underline{F}$=4.59, (2,56), $p < .05$). Again, this interaction arose due to a significant difference in just the first block of practice between the separate and compound response mappings. In block 1, the separate response mapping (6668 msec. per target) was considerably slower than the compound response mapping (5725 msec. per target). There were no significant differences between the separate and compound response mappings for total time per target performance in blocks 2 or 3 of practice. There was also a significant main effect for the blocks of practice in the analysis of blocks 1-3 where total response time per target was significantly longer in block 1 as compared to blocks 2 and 3, ($\underline{F}$=8.18, (2,56), $p < .01$). The analysis of total time per target for blocks 1-3 also generated a significant interaction effect for the separate-compound target-task manipulation and target density, ($\underline{F}$=74.4, (2,56), $p < .01$). The effect was due to all levels of the separate target-task being different from each other at all levels of target density while the compound target-task conditions were not different from each other. This interaction is consistent with the findings of the analysis of total time per target and the relationship shown in Figure 6-6. Further, there were significant main effects for the target-task contrast itself, ($\underline{F}$=208, (1,28), $p < .01$), where the compound targets, (8190 msec. per target), were identified slower than were the separate targets, (3857 msec. per target); and the target density, ($\underline{F}$=354, (2,56), $p < .01$), where the rate of target identification decreased as the number of targets increased.

The analysis for total time per target for blocks 4-10 eliminated all practice effects. There were significant main effects for the separate-compound target-task conditions, ($\underline{F}$=42.6, (1,32), $p < .01$), and target density, ($\underline{F}$=56.0, (2,64), $p < .01$). On average, the compound targets, (7757 msec. per target), were identified more than twice as slowly as the separate targets, (3554 msec. per target), and the more targets there were to be identified, the slower they were identified, (3388, 5561 and 8018 msec. per target for the 2, 3 and 4 targets conditions). Finally, there was a significant target-task by number of targets interaction where the rate of increase for the compound target-task condition was significantly greater as the target density increased than was the separate target-task condition, ($\underline{F}$=108, (2,64), $p < .01$).

Input Time. Figure 6-9 shows the general results for the analysis of the input time per target data for blocks 1-10. All four main effects were significant. The separate target-task condition was significantly different from the compound target-task condition, (1940 versus 3650 msec. per target, $\underline{F}$=111, (1,26), $p < .01$), and the separate response mapping was significantly slower than the compound response mapping, (3021 versus 2569 msec. per target, $\underline{F}$=7.77, (1,26), $p < .01$). Further, all three levels of the target density were significantly different from each other, (1660, 2691 and 4034 for the 2, 3 and 4 targets conditions; $\underline{F}$=330, (2,52), $p < .01$), and blocks 1 and 2 of practice were significantly slower than blocks 3-10 (2785, 2699 msec. per target for blocks 1 and 2 versus 2609 msec. per target over blocks 3-10, $\underline{F}$=2.15, (9,234), $p < .05$).

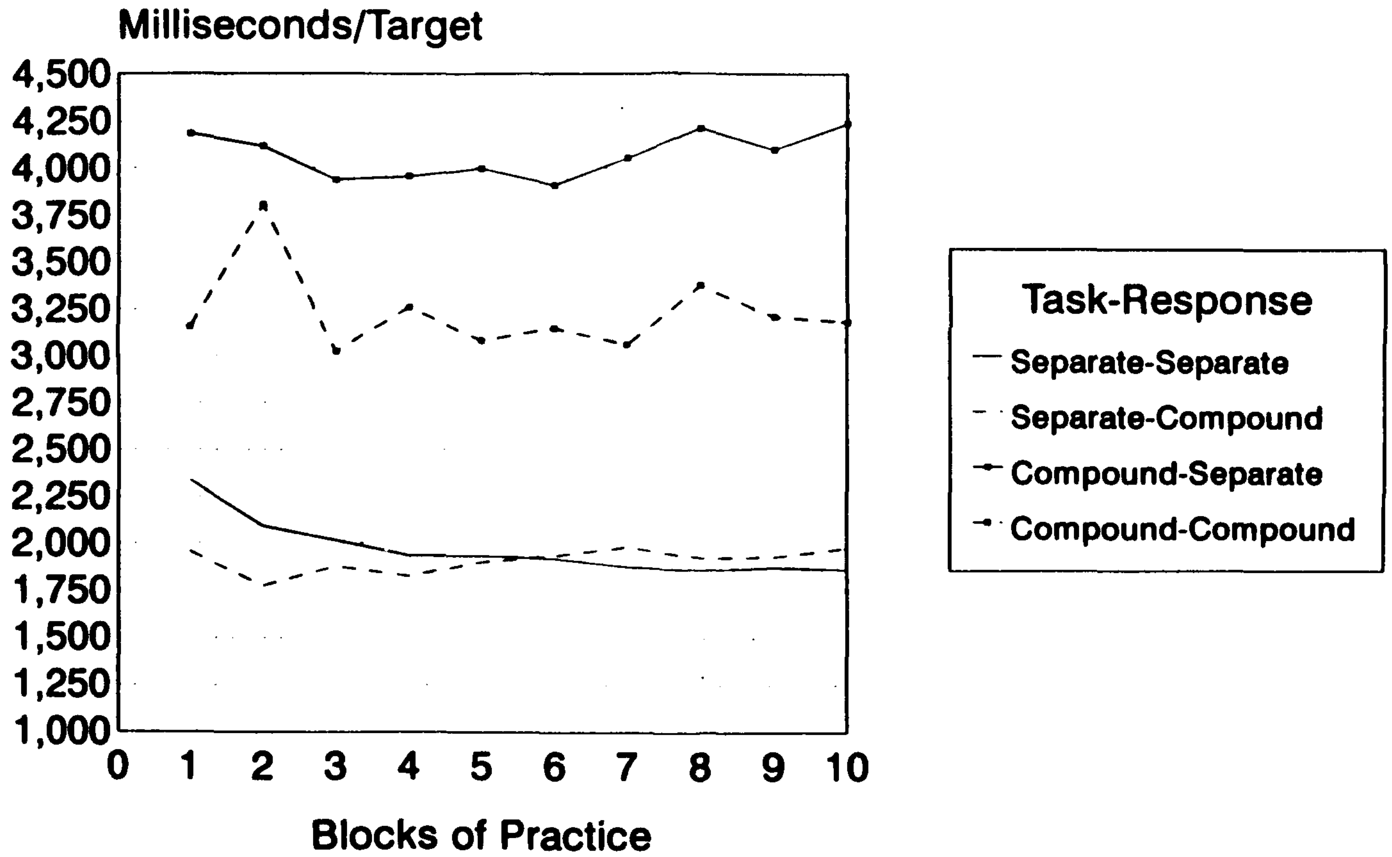
There were also five significant interaction effects in the input time per target data over all 10 blocks. The highest order significant interaction was a three-way interaction between the separate-compound target-task conditions, response mapping and blocks ($\underline{F}$=2.14, (9,234), $p < .05$). This interaction, as may be seen in Figure 6-10, was significant because: 1) there were significant differences between the separate and compound response mappings in both blocks 1 and 2 of practice for the separate target-task conditions; and 2) there were significant differences between the

Figure 6-9. Separate, Compound:
Input Time



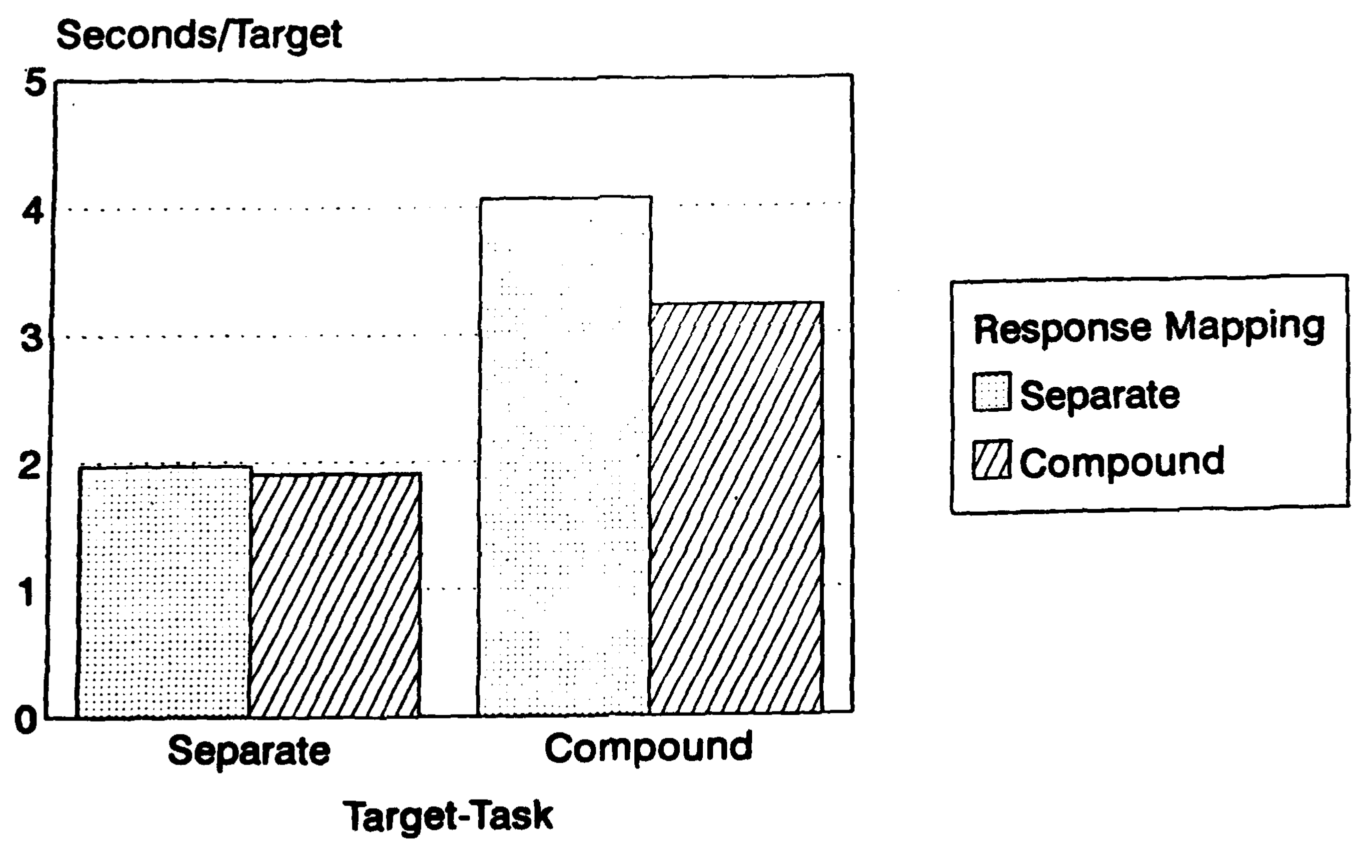
30 July 1992

Figure 6-10. Separate, Compound: Input Time Condition by Response Mapping by Blocks Interaction



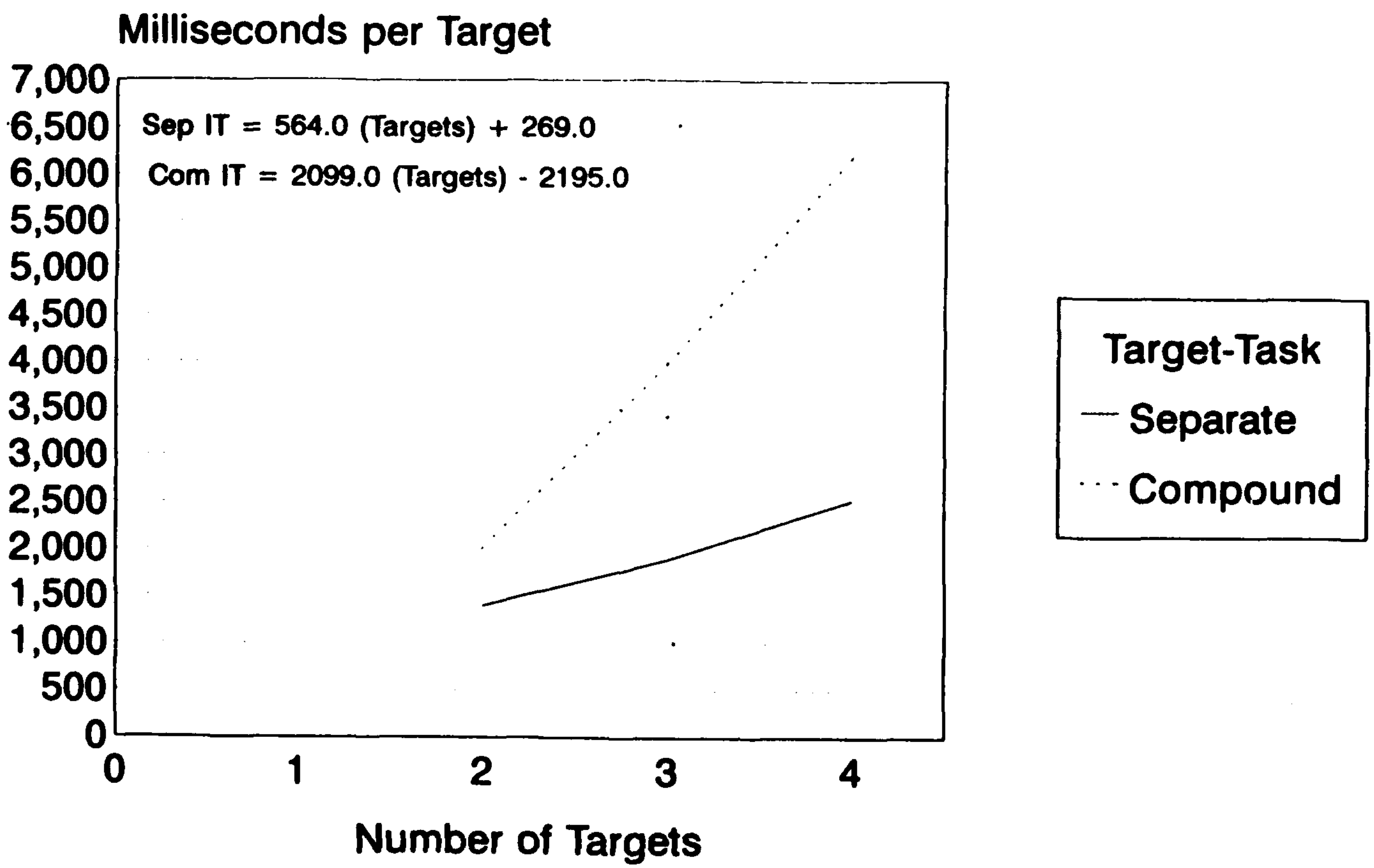
30 July 1992

Figure 6-11. Separate, Compound: Input Time
Target-Task by Response Mapping Interaction



19 September 1992

Figure 6-12. Separate, Compound:
Input Time Target-Task by Number of Targets Interaction.



2 April 1992

separate and compound response mappings in blocks 1, and 3-10 for the compound target-task conditions. As for the significant two-way interactions, the separate-compound target-task by response mapping interaction was significant, ($F=5.75$, (1,26), $p < .01$). This interaction is shown in Figure 6-11. The interaction resulted because, while the response mapping had no significant effect on the rate of input for the separate targets, the separate response mapping caused the input of the compound targets to be significantly slower than it was for the compound response mapping, (1971 msec. per target versus 1908 msec. per target for the separate and compound response mappings for the separate target-task conditions, and 4070 msec. per target versus 3230 msec. per target for the compound target-task conditions with the separate and compound response mappings, respectively). The target-task by target density interaction (Figure 6-12) was significant, ($F=90.1$, (2,52), $p < .01$), because the rate of increase in input time per target as the target density increased was 3.7 times greater with the compound target-task conditions than it was with the separate target-task conditions. The relationship of the target-task conditions as a function of the target density is described by the regressions:

$$\text{Input Time}_{\text{Separate Target-Task}} = 564.0 \text{ (Number of Targets)} + 269.0, \text{ and}$$

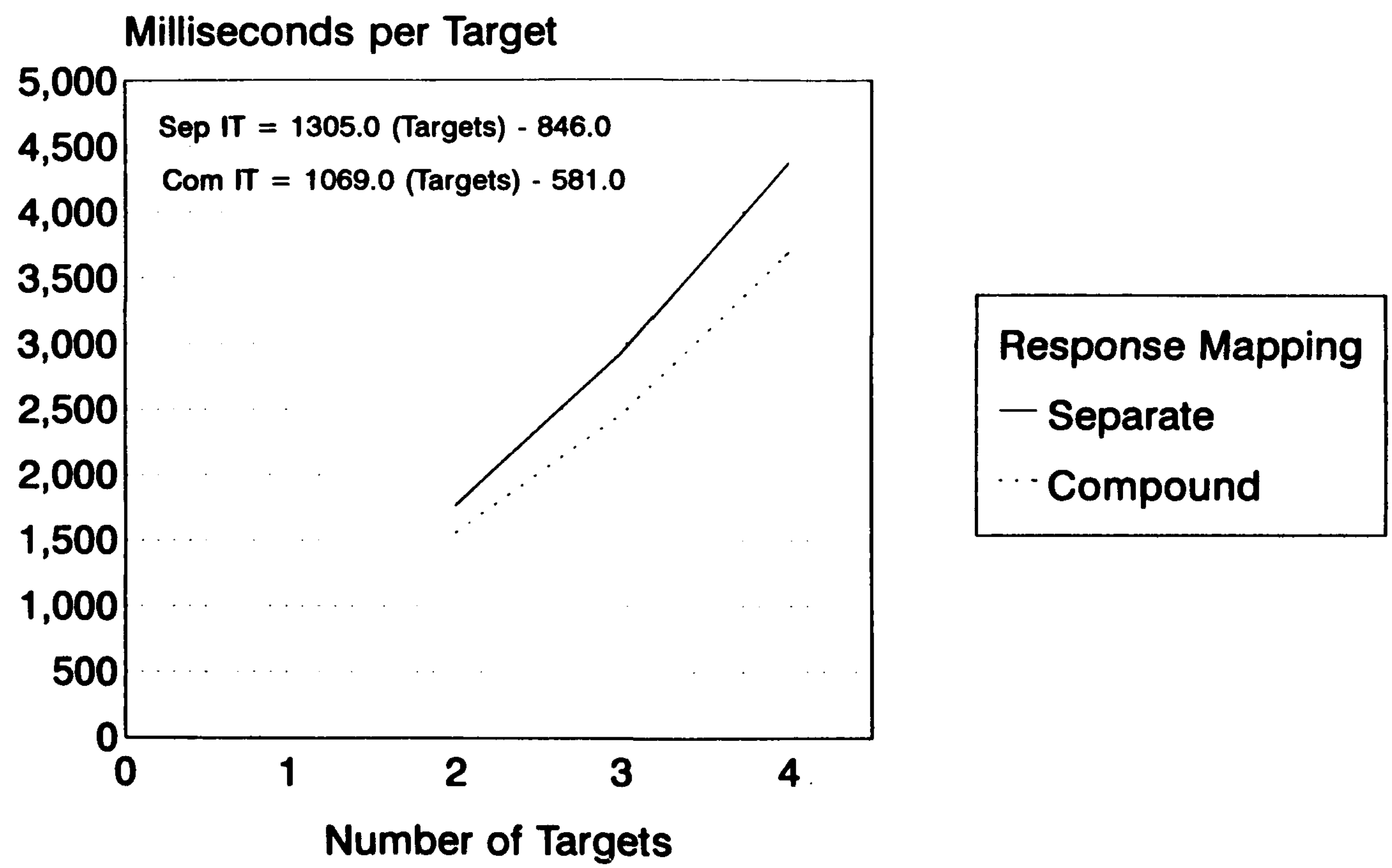
$$\text{Input Time}_{\text{Compound Target-Task}} = 2099.0 \text{ (Number of Targets)} - 2195.0.$$

The response mapping by target density interaction (Figure 6-13) was significant for the input time per target data over all blocks as well, ($F=3.27$, (2,52), $p < .05$). As with the target-task by target density, the interaction is a product of the rate of reading targets from the display and encoding them into memory decreasing 1.2 times more rapidly with the separate response mapping as the number of targets increased, than it did with the compound response mapping, i.e.:

$$\text{Input Time}_{\text{Separate Response Mapping}} = 1305.0 \text{ (Number of Targets)} - 846.0, \text{ and}$$

$$\text{Input Time}_{\text{Compound Response Mapping}} = 1069.0 \text{ (Number of Targets)} - 581.0.$$

Figure 6-13. Separate, Compound:
Input Time - Response Mapping by Number of Targets Interaction.



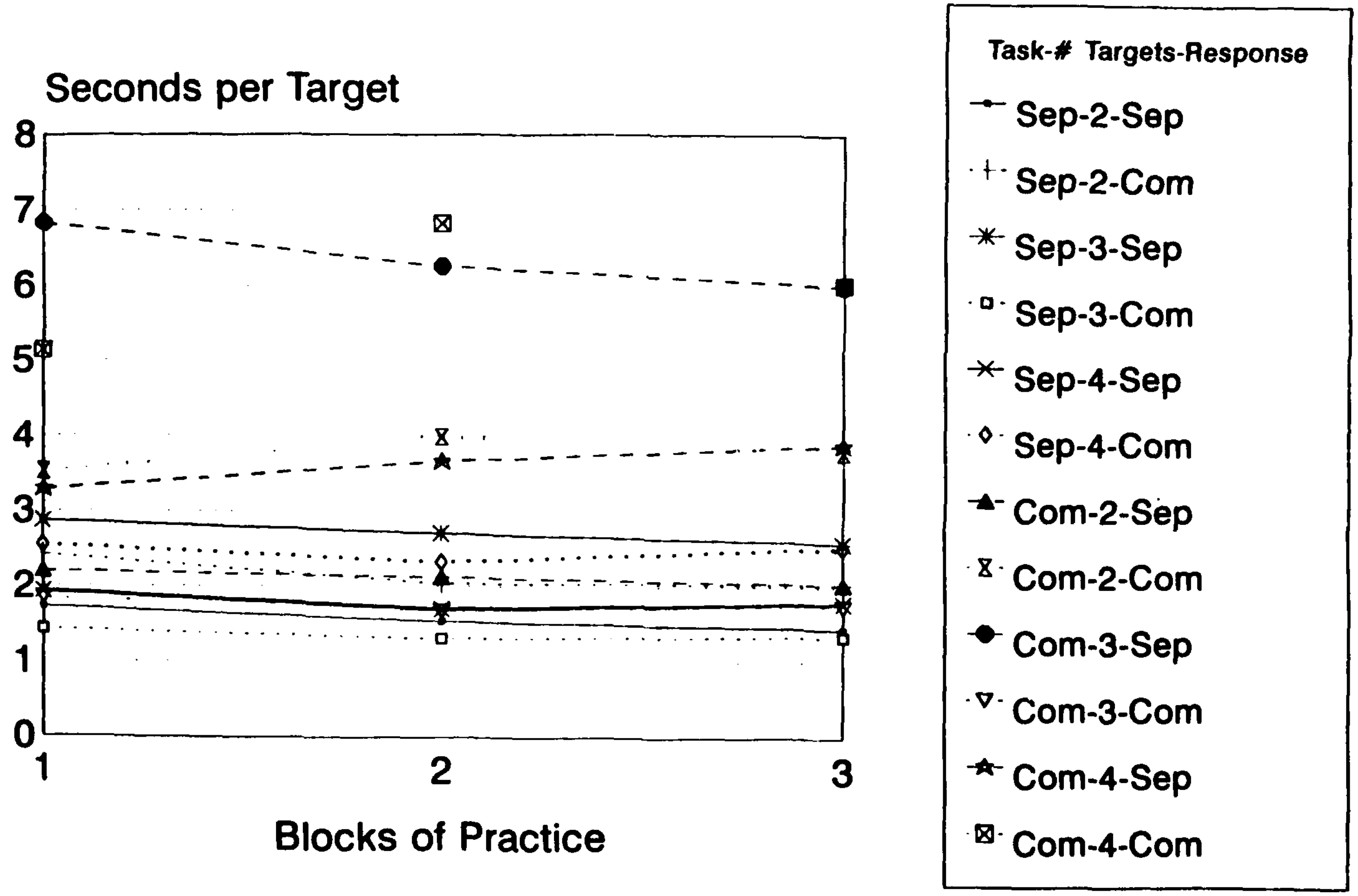
6 April 1992

Finally, there was a significant target-task by blocks interaction, ($\underline{F}$=5.75, (9,234), $p < .05$). Reexamining Figure 6-10 shows that this interaction is a result of a significant reduction in the input time per target over the first three blocks for the separate target task condition, while the compound target task condition did not improve significantly.

The results for the analysis of input time per target over blocks 1-3 eliminated two of the significant main effects. The separate-compound target-task manipulation remained significant, ($\underline{F}$=123, (1,28), $p < .01$), as did the target density, ($\underline{F}$=354, (2,56), $p < .01$). As with the analysis over all blocks, the separate target-task condition was faster than the compound target-task condition, (2009 versus 3938 msec. per target), and all three levels of number of targets were significantly different from each other, (1699, 2842 and 4380 msec. per target for the 2, 3 and 4 targets conditions).

The analysis for input time data from blocks 1-3 generated a number of significant interaction effects, many of which were different from those seen for the analysis over blocks 1-10. There were two-way interactions for the target-task comparison and target density effect, ($\underline{F}$=76.5, (2,56), $p < .01$), the target-task comparison and blocks effect, ($\underline{F}$=4.06, (2,56), $p < .05$), and finally the response mapping and blocks effect, ($\underline{F}$=3.92, (2,56), $p < .05$). As with the analysis for input time per target for blocks 1-10, the target-task by target density effect reflects the compound target-task condition becoming much slower relative to the separate target-task condition as the target density increased. The target-task by blocks interaction for blocks 1-3 confirmed that the separate target-task condition improved significantly through the first three blocks while the compound target-task condition did not appreciably change. The response mapping by blocks interaction reflected an improvement in the rate of reading-in of information from the display and encoding it into memory with the separate response mapping, while there was no significant change in the compound response mapping. The data from input time per target over blocks 1-3 also revealed a significant

Figure 6-14. Separate, Compound:
Input Time - Blocks 1-3 Interaction for
Contrast by Response Mapping by Number of Targets



30 July 1992

three-way interaction between response mapping, number of targets identified and blocks, ($\underline{F}$=2.84, (4,112), $p < .05$). This interaction was due to there being a significant difference in the input time per target for identifying 4 targets in block 1 for the separate and compound target-task conditions, while there were no significant differences between the separate and compound target-task conditions in blocks 2 and 3 of practice. Examination of Figure 6-9 shows that while the mean difference between the two target-task groups actually increased in block 2 relative to block 1, the variability of performance was actually much higher in the second and third blocks than it was in block 1. Finally, there was a four-way interaction between the target-task comparison, response mapping, target density and blocks in the input time per target data from blocks 1-3, ($\underline{F}$=3.36, (4,112), $p < .05$). This interaction (Figure 6-14) was complex and involved two factors. First, the identification of four compound target-task targets with the compound response mapping slowed significantly from block 1 to block 2 and increased significantly from block 2 to block 3. Overall, however, the input time per target performance slowed slightly from block 1 to 3. Most of the target-task by response mapping by number of targets conditions slowed slightly, or stayed the same, as measured by input time per target from block 1 to block 3 of practice. A second contributing factor to this interaction was the significant improvement in performance for the identification of three compound target-task targets when using the separate response mapping from blocks to 3, particularly when compared to the other target-task by response mapping by target density conditions. In summary, the four-way interaction between target-task condition, response mapping, target density and blocks over blocks 1-3 resulted because the performance early in practice was unstable, and no consistent pattern of change appeared over these first three blocks.

The results of the input time per target analysis for c ta from blocks 4-10 are much less complex than those from the overall analysis or the analysis for blocks 1-3. There were two significant main effects for the analysis of input time data from blocks 4-10. The separate versus compound target-task conditions was significant, ($\underline{F}$=184, (1,32), $p < .01$; with the separate target

task having an average input time per target of 1910 msec. per target and compound having an average of 3884 msec. per target over blocks 4-10). The target density was significant at all three levels, ($\underline{F}$=399, (2,64), $p < .01$; 1663, 2802 and 4226 msec. per target for the 2,3 and 4 target conditions). There was one significant interaction for the input time per target data over blocks 4-10, ($\underline{F}$=124, (2,64), $p < .01$). As with the analysis for input time per target over all blocks (Figure 6-12), this effect was due to the rate of input slowing for the compound target-task condition with increases in the target density much more rapidly than it did for the separate target-task condition. There were no other significant effects for the input time per target data over blocks 4-10.

Output Time. The analysis of output time per target data for blocks 1-10 (Figure 6-15) resulted in three significant effects. The target density effect was significant due to the 2 targets condition (560 msec. per target) being significantly faster than the three or four targets conditions (604 and 623 msec. per target; $\underline{F}$=14.0, (2,52), $p < .01$). The blocks main effect was also significant, ($\underline{F}$=12.36, (9,234), $p < .01$), with both blocks 1 and 2 being significantly different from each other and the other blocks, (718, 625 msec. per target for blocks 1 and 2 versus an average of 577 msec. per target for blocks 3-10). Finally, as shown in Figure 6-16, there was one significant interaction involving the response mapping and target density, ($\underline{F}$=4.72, (2,52), $p < .05$). This effect was due to the compound response mapping being significantly faster than the separate response mapping when 2 targets were being identified, and significantly slower when four targets were identified. The interaction is described by the regressions:

$$\text{Output Time}_{\text{Separate}} = 18.0\ (\text{Number of Targets}) + 560.0,$$

$$\text{Output Time}_{\text{Compound}} = 58.5\ (\text{Number of Targets}) + 424.0.$$

The analysis for the output time per target data in blocks 1-3 resulted in three significant main effects. First, the separate-compound target-task comparison effect was significant ($\underline{F}$=6.70,

Figure 6-15. Separate, Compound: Output Time

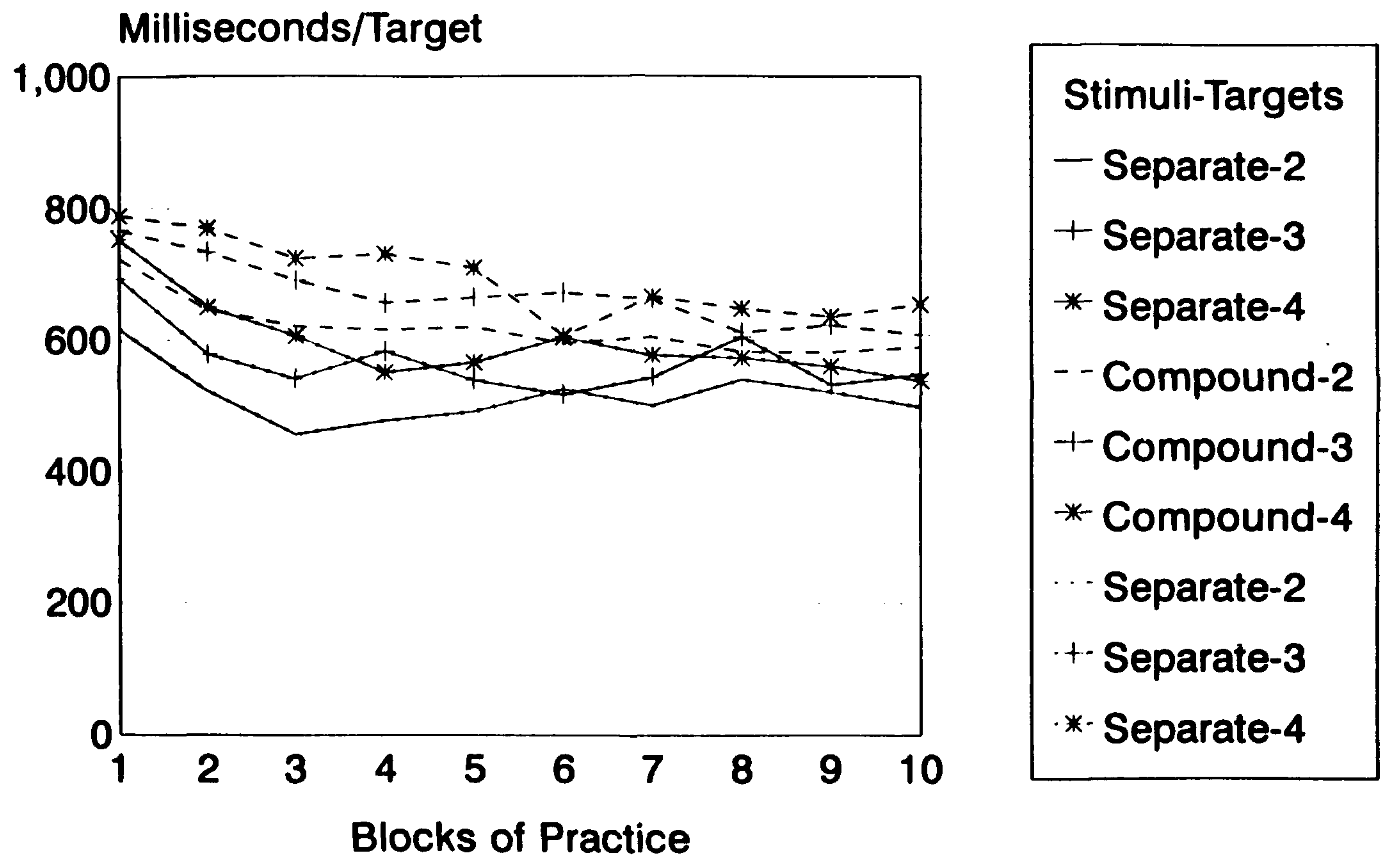
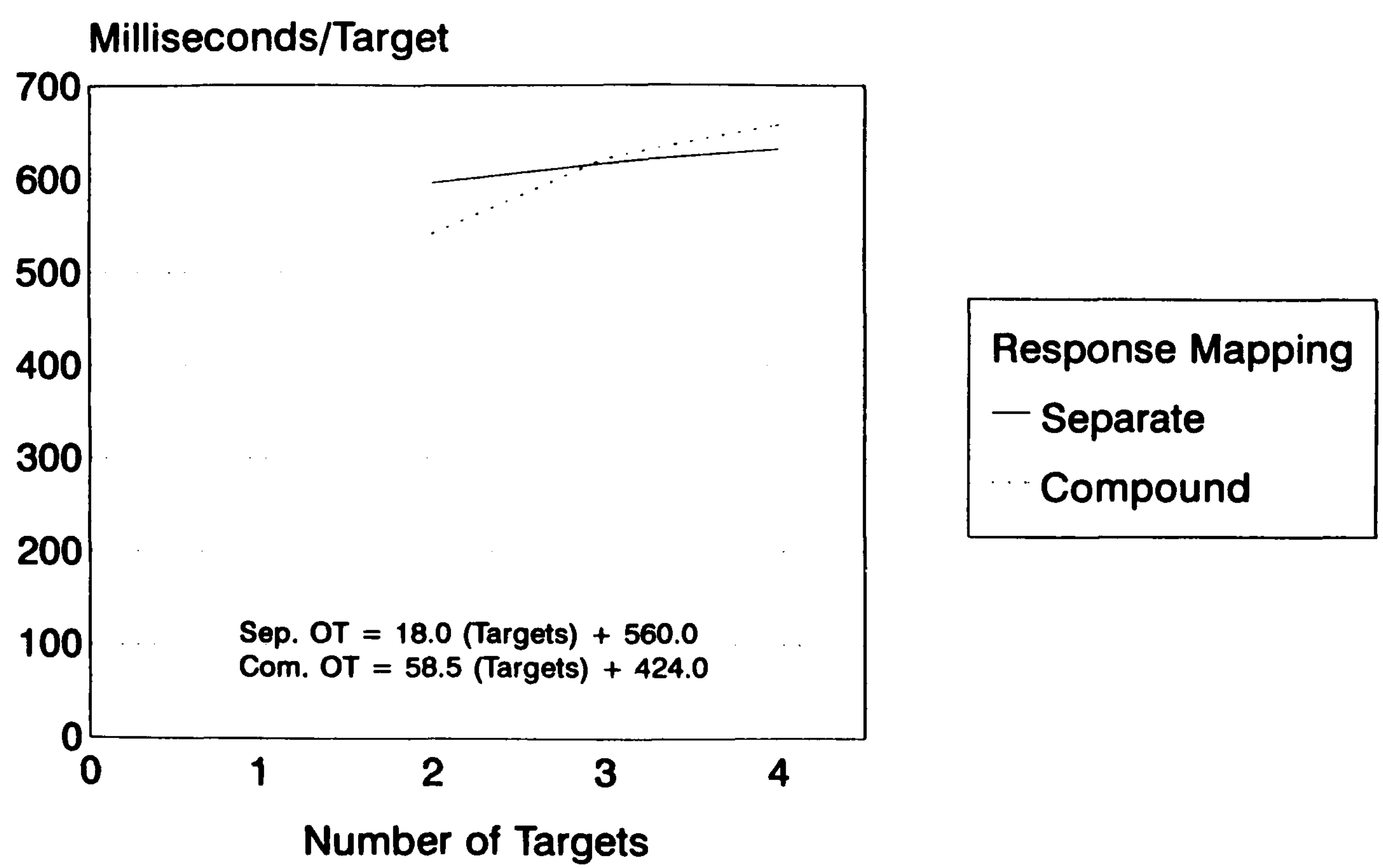
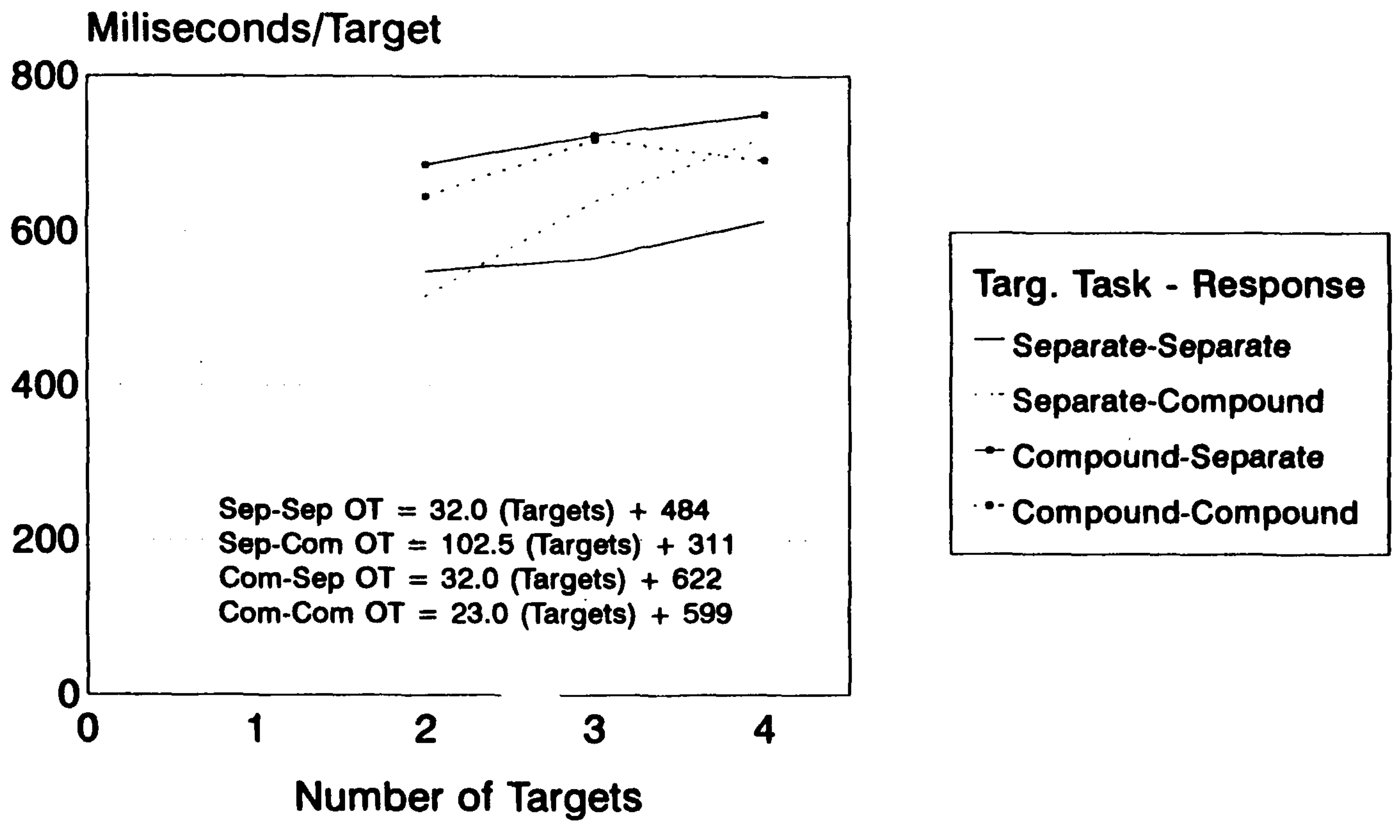


Figure 6-16. Separate, Compound: Output Time Response Mapping by Number of Targets Interaction



3 April 1992

Figure 6-17. Separate, Compound: Output Time Condition by Response Mapping by Number of Targets Interaction, Blocks 1-3.



7 April 1992

(1,28), $p < .05$; 600 msec. per target for the separate target-task, and 703 msec. per target for the compound target-task). Target density was significant, ($\underline{F}=19.1$, (2,56), $p < .01$), with all three levels being significantly different from each other (599, 662 and 694 msec. per target for the 2, 3 and 4 targets conditions). There was a significant improvement over all three blocks, (719, 635 and 600 msec. per target for blocks 1, 2 and 3; $\underline{F}=29.3$, (2,56), $p < .01$). In addition, there were two significant interaction effects which are illustrated in Figure 6-17. The first was a three-way interaction between the target-task conditions, response mapping and the target density, ($\underline{F}=3.29$, (2,56), $p < .05$). The effect is due to no significant difference between the separate and compound response mappings at each level of target density for the compound target-task conditions, while there was a significant difference between the separate and compound response mappings when 3 or 4 separate target-task targets were identified. This effect was sufficiently strong that when the response mapping manipulation was ignored, there was still a significant two-way interaction effect for the target-task conditions and target density, ($\underline{F}=3.69$, (2,56), $p < .05$). The regressions for the three-way interaction are[16]:

$$\text{Output Time}_{\text{Separate-Separate}} = 32.0\ (\text{Number of Targets}) + 484,$$

$$\text{Output Time}_{\text{Separate-Compound}} = 102.5\ (\text{Number of Targets}) + 311,$$

$$\text{Output Time}_{\text{Compound-Separate}} = 32.0\ (\text{Number of Targets}) + 622,$$

$$\text{Output Time}_{\text{Compound-Compound}} = 23.0\ (\text{Number of Targets}) + 599.$$

The analysis for output time per target over blocks 4-10 generated two significant main effects. The first was for the separate versus compound target-task conditions, ($\underline{F}=5.74$, (1,32), $p < .05$; 541 versus 639 msec. per target). The second was for the target density with the 2 targets condition being significantly faster than the 3 and 4 targets conditions, (558, 597 and 616 msec. per target for the 2,3 and 4 target conditions, $\underline{F}=11.1$, (2,64), $p < .01$). Finally, there was one significant

[16]The subscripts in these equations denote the target-task condition, and then the response panel mapping condition.

interaction. between the response mapping and target density effects, ($F = 5.61$, $(2,64)$, $p < .01$). As with the analysis for all blocks, the effect was due to the compound mapping being significantly faster than the separate response mapping when two targets were being identified, and significantly faster when four targets were being identified (see Figure 6-16).

DISCUSSION

The results of this study demonstrate that there are differences in performance in an identification task depending on the use of targets consisting of one versus two codes, when all the codes in the targets are relevant to the identification task. The effects which give rise to this conclusion are subtle and complex, and will be sorted out in detail below in terms of the implications for performance with these particular conditions, the experimental predictions and the ramifications of these findings on application, methodology and theory. The results will not be interpreted in terms of the particular codes used, or the code categories used, because Chapters 4 and 5 deal extensively with those issues. Rather, this research focuses on the impact of code complexity on performance in an identification task and the main manipulation concerning the number of codes to be identified within each target. For this reason the two target-task conditions employed in this study use exactly the same subsets of alphanumeric codes to create the different target code combinations. The separate target-task condition had a single alphanumeric code per target presented on the display. The compound target-task condition had two alphanumeric codes per target, (a digit and a letter). In addition, as with the studies described in Chapters 4 and 5, the response mapping was manipulated, as was the number of targets being presented on the display, and the dependent measures were calculated for each of the 10 blocks. The results as measured by each of the four dependent measures will now be discussed in turn.

Dependent Measures

Percent Correct. The accuracy data for this study was much less stable than that seen in the studies described in Chapters 4 and 5, with an overall average of 89.3% of the trials being performed

Table 6-4. Separate, Compound: Differences for Significant Main Effects for Blocks 1-10.

Significant Effect	Actual Change	% Change	Actual Change	% Change
	Percent Correct	Percent Correct	Total Time	Total Time
---------------	------------------	------------	------------------	------------
Comparison:				
Separate-Compound	-13.4	-16.2%	3834	205.0%
Response Mapping:				
Separate-Compound	--	--	--	--
Targets: 2-4	-18.6	-23.6%	4444	231.2%
Blocks: 1-10	--	--	795	-15.9%
******************	************	************	*************	************
	Input Time	Input Time	Output Time	Output Time
--------------	------------	-----------	-----------	------------
Contrast:				
Separate-Compound	1710	188.1%	--	--
Response Mapping:				
Separate-Compound	-452	-17.6%	--	--
Targets: 2-4	2374	243.0%	63	111.3%
Blocks: 1-10	-120	-4.5%	-160	-28.7%

Actual Time in MSec./Target. Group means used to generate this Table may be found in Appendix B.
% Change = Actual Change / (Larger of the mean times for that comparison).
30 July 1992. Empty cells indicate the effect was not significant at $p < .05$.

correctly. Therefore, there is no basis to assume the presence of significant floor or ceiling effects in the accuracy data. Further, there were a variety of significant effects for the accuracy dependent measure, i.e. percent of correct responses within a ten-trial block of practice. Accuracy of target identification was affected by the target-task manipulation, with worse performance for the compound target-task than for the separate target task. This was expected given the greater number codes to be identified when compound targets were present to be identified. In fact, Table 6-4 shows that there was a net decrease in accuracy for the separate versus compound target task condition of 16.2%. Further, identification accuracy decreased as the number of targets increased, (a drop of 23.6% overall), and the significant target-task conditions by number of targets to be identified interaction showed that the rate of decrease in accuracy was significantly greater for the compound target-task condition than it was for the separate target-task condition. On the basis of these findings, it may be concluded that the identification of the additional codes inherent in the use of the compound target-task generates a significant and persistent cost in identification performance as measured by accuracy, and the greater the number of targets the greater the cost. Finally, there was an effect on identification accuracy due to the response mapping. This appeared in the form of a significant three-way interaction between the response mapping, number of targets identified and blocks of practice. This effect shows that there was a cost associated with using the compound response mapping, in terms of performance accuracy, when the task was relatively novel. The cost apparently disappeared with sufficient practice. The effects seen in the accuracy data were essentially consistent in the analysis of performance early in practice (blocks 1-3) and late in practice (blocks 4-10).

Total Time per Target. The latency data produced very complicated results both in terms of the three latency dependent measures, and the effects for over all blocks, early and late practice. Overall, the compound target-task condition was 3834 msec. per target, (or 205%), slower than the separate target task condition. A similar significant effect was found both early and late in practice.

Thus, it can be concluded that the identification of twice as many codes per target effectively doubles the time required per target in an identification task. There was also a significant overall latency effect for the number of targets identified, with an increase of 4444 msec. per target overall in identifying four rather than two targets. This translates to a 231.2% decrease in the rate of target identification as the number of targets was doubled. Again, the number of targets effect was consistent in the analyses for data from blocks 1-3 and 4-10. This finding suggests that there are processing costs associated with identifying multiple targets above and beyond those of identifying the codes per se. If the decrease in the rate of target identification total time per target were a simple product of the number of codes being identified per target and the target density, then the identification of twice as many targets would lead to a change on the order of 200-210% given the change seen in the target-task conditions. A change of 231% indicates there is a significant additional cost in the processing of additional targets than would be expected based on the number of codes being processed alone[17]. The final main effect in total time per target was for blocks. Overall, there was a drop in total time per target of 795 msec. per target, or a drop of 15.9%. This confirms that performance does indeed improve with practice. Further, comparing the effects due to practice for this data with that reported in Table 4-4 in Chapter 4, shows that this change is virtually identical with that seen for the identification of single digits and single letters codes (15.5%). Comparing this result to that seen for practice for total time per target over blocks 1-10 in Chapter 5, Table 5-4 shows a similar result (19.2%). Therefore, the rate of learning appears to be constant regardless of what the particular task requirements in an identification task might be.

There were a variety of significant interaction effects for total time per target. First, the target-task manipulation showed a significant interaction with the response mapping manipulation.

---

[17]Since twice as many codes were present in the compound target-task conditions as there were in the separate target-task conditions, a change in performance of 200% would indicate that the amount of processing was required on a per code basis. A change of 231% indicates that there was a 31 % (231-200) increase in processing over what would have been expected on a per code basis.

While there was no significant main effect for the response mapping in the total time per target data, the interaction showed that the identification of the compound target-task targets was significantly slower with the separate response mapping than it was with the compound response mapping. Further, the significant three-way interaction for target-task, response mapping and target density showed that this effect was due to those conditions where three or four targets were being identified. Therefore, it may be concluded that the identification of large numbers of compound targets are identified most rapidly with a compound panel mapping. Further, this result makes it quite clear that the factors relating to the output side of the task can, and do, impact the way information is read from a display and encoded into memory. The finding that compound targets are identified more quickly with the compound response mapping is consistent with the notion of Stimulus-Response compatibility (Fitts & Seeger, 1953), as well as demonstrating that the response side of a task impacts the input side of the task.

There were a number of significant practice effects for the total time per target data. First there was a targets by blocks effect, (Figure 6-7), where the rate of target identification for conditions with more targets were improved significantly more by extended experience with the task. Second, there was a response mapping by target density by blocks interaction where the identification of four targets, using the separate response mapping, was significantly slower than the identification of four targets using the compound mapping in both blocks 1 and 10. This suggests that the overall performance using the separate response mapping with a large number of responses is more difficult when the users have had minimal experience with the task, and further that users are more likely to exhibit deficits in performance due to time on task with the separate response mapping, as measured by total response time. Finally, there was a four-way interaction between target-task, response mapping, target density and blocks in the total time per target data from blocks 1-10. This effect, (Figure 6-8), was due to the identification of targets with the separate response mapping being significantly slower when compound targets were being identified, than it was with

any of the other target-task by number of targets by response mapping conditions in block 1 of practice. In practical terms, the identification of the codes in four, compound targets using the compound response mapping is significantly faster than the comparable task with the separate response mapping, particularly when the task is novel. However, after fairly minimal experience with the tasks, performance becomes comparable between the separate and compound target-task conditions, and the differences between the response mappings are not significant.

Input Time per Target. Partitioning of time on task into blocks 1-3 and 4-10 generated results generally consistent with the results described for blocks 1-10. The response mapping by number of targets interaction remained significant in blocks 1-3, confirming the interpretation that the cause of the interaction was the separate response mapping being significantly slower in block 1 of practice when four targets were being identified. The analysis for blocks 4-10 eliminated all practice effects, which was the intention in partitioning the data into early and late practice. This confirmed that the majority of the time on task effects reflect learning to perform the identification tasks, and these effects are largely complete within 30 trials.

The analyses for input time per target showed that the largest portion of the effects seen in total time per target are due to the reading of codes from the display and encoding them into memory. All four main effects were significant, and the absolute and relative magnitude of change for these effects may be seen in Table 6-4. The input of the compound target-task targets took nearly twice as long, (exactly 1.88 times as long), as the input of the separate target-task targets, or an actual change of 1710 msec. per target. The direction and size of this effect was predicted due to there being twice as many relevant codes in the compound target-task conditions, and there being a net savings in input time per target due to these two codes being readable with a single visual fixation. In fact, using the regression for input time per target with the separate target-task condition, shown in Figure 6-12, it may be seen that the input time per target for eight independent

(separate) targets would be 4781 msec. per target. Comparing this to the identification of four compound targets, (6201 msec. per target), we find that there is a net difference in the predictions of 1420 msec. per target. This difference represents a total savings in dwell time for not having to locate *four* additional separate targets. Therefore, dividing this number by 4 will generate an estimate of saccadic movement between each dwell, i.e. 355 msec. per target. This is very close to the 100-300 msec. range described as typical for reading information from simple (non-information) targets in a visual display (Young & Sheena, 1975). This finding supports the interpretation that the processing of targets from the separate and compound target-task conditions is identical, despite the increase in the number of codes and alternative arrangement of codes within targets, and that the shorter mean input time per target seen for the compound target task is due to the savings in eye movement times between fixations.

Of particular interest was the unusual significant main effect due to the response mapping for the input time per target data. In the previous studies, (Chapters 4 and 5), the impact of the response mappings was shown only in the form of significant interactions between the response mapping manipulations and other factors. However, in the comparison of the separate and compound target-task conditions, the compound response mapping proved to be 452 msec. per target (17.6%) faster than the separate response mapping. While it was not intuitively expected that the compound response mapping would result in faster performance than the separate response mapping, the important aspect of this result is that it clearly proves that the output side of the task can and does affect the way information is read from the display and encoded into memory. Further, it may have implications for stimulus-cognition-response (S-C-R) compatibility, (Wickens, 1984), which will be discussed in detail below. There was a three-way interaction between the separate-compound target-task conditions, response mapping, and blocks. This effect showed that major contributions to the response mapping effect were: 1) that there is a distinct disadvantage in identifying compound targets with the separate response mapping in blocks 1, and 3-10; and 2) that

there was a disadvantage early in practice when identifying the separate targets with the separate response mapping relative to the compound response mapping. Thus, the compound response mapping resulted in no improvement with practice, while the performance with the separate response mapping did improve with practice when the separate targets were being identified. The recommendation for the use of separate and compound response mappings suggests that if all the codes on the response mapping are relevant to the task being performed, the mapping of multiple codes to single response keys holds some advantage (as measured by input time) relative to the placement of a single code per response key.

As might be expected based on the discussion above, there were significant block effects and density effects. Table 6-4 shows that there was an overall increase in input time per target of 2374 msec. per target, or 243% as the target density was doubled. This increase was roughly that which was expected based on a doubling of the target density. Considering the very demanding nature of identifying four, compound targets, i.e. eight codes, and the demands this places on short-term memory (Miller, 1956), it is not surprising that in fact the increase in time per target was greater than double that seen with two targets. This additional time required per target when four targets were being identified is best explained in terms of the additional time required to encode and maintain the codes in memory. The practice effect showed that there was a decrease of 120 msec. per target or 4.5% over blocks 1-10. This was a significant, but very small improvement in input time per target. The surprisingly small size of the effect is explained by the significant interaction effects for blocks and the other factors described in detail above.

The analyses for input time per target in blocks 1-3 and 4-10 served their purpose in terms of confirming the nature of the practice effects. The analysis of blocks 1-3 removed the significant main effects for the response mapping and blocks, which had been largely attributed to a blocks manipulation in the overall analysis, and therefore should have been eliminated. The result of this

partitioning of the time on task, however, was to generate three- and four-way interactions involving the practice effect and response mapping. The four-way interaction, which subsumed the three-way interaction, involved the target-task conditions, response mapping, target density and blocks effects. The interaction shows that the performance of four targets early in practice was unstable, and did not generate a steady improvement in performance early in practice (i.e. blocks 1-3). Thus, the effect occurred because the identification of four compound targets with the compound response mapping went from being significantly better in block 1, and then significantly worse in block 2, than the identification of the four compound targets with the separate response panel. The significant effects found in the analysis for blocks 1-3 was entirely consistent with that described for the analysis over all blocks.

Output Time per Target. The output time per target data was remarkable mainly in that it showed so few significant effects. The target-task conditions had no significant effect as measured by the output time per target data over all blocks. The type of response mapping showed one significant effect on output time, and that was as measured through a significant response mapping by number of targets interaction. The interaction showed that the time required to take each target code from memory, translate it into and then execute a response was 3.25 times slower for the compound response mapping than it was with the separate response mapping for each additional target identified. Thus, the rate of target identification decreased much faster with each additional response for the compound response mapping than it did with the separate response mapping, as shown by the regressions in Figure 6-16. There were also the typical significant main effects for the number of targets identified, where the rate of target identification decreased as more targets were to be identified, and for the blocks effect where performance improved 28.7% between blocks 1 and 10. The bottom line in terms of output is that the more targets being identified, the slower the output with the compound response mapping as compared to the separate response mapping. This

is exactly the opposite result seen for type of response mapping as measured by input time per target.

The output time per target for blocks 1-3 generated a significant main effect for the separate-compound target-task comparison, in which the separate target-task condition was output 103 msec. per target (17.2%) faster than the compound target-task condition. Again, this result is at odds with that seen for input time per target where the compound condition was 17.6% faster than the separate condition. The blocks and number of targets effects remain significant in the analysis of output time per target for blocks 1-3. Another effect that was different for the output time per target data in the analysis of blocks 1-3 as compared to blocks 1-10 was a significant three-way interaction between target-task, response mapping and target density. The effect was largely due to a different rate of increase for the identification of separate targets using the compound response mapping, which (as shown in Figure 6-17) increased 102.5 msec per target^2 as opposed to an increase on the order of 30 msec. per target^2 for the other target-task by response mapping conditions early in practice. As with the other dependent measures, the analysis for output time per target over blocks 4-10 did not generate any surprising effects, and effectively removed all time-on-task effects.

Experiment Manipulations

Target-Task Manipulation. Summarizing the results in terms of the factors manipulated, it is clear that the target-task manipulation had an effect on performance as measured by both speed and accuracy of target identification. The performance with the compound target-task conditions were both less accurate and slower, than the performance with the separate target-task conditions. The difference in time per target appeared for the target-task manipulation consistently appeared only in the total time and input time per target measures. Any effect due to the target-task manipulation, as measured by output time per target, appeared only very early in practice.

Target density. The more targets there were to identify, the slower and less accurate the performance as measured by both time per target and overall accuracy. This effect was consistent across all four dependent measures. Further, there was a significant interaction between the number of targets identified and the target-task manipulation as measured by accuracy, total time per target, and input time per target. As more targets were to be identified, the less accurate and more slowly targets were identified, particularly for the compound target-task condition. Thus, performance clearly got worse, faster for the compound target-task condition when more targets were to be identified than it did for the separate target-task conditions. That this effect should have a locus entirely in input time supports the assumptions of the WiTS processing model; i.e. that the information in a display is read in and encoded into memory during input and in the process is translated to a form which facilitates processing in memory as required by the task demands. It can be concluded that the latency and accuracy performance decrements associated with processing the codes in an identification task are chiefly associated with the reading of information from a display and encoding them into memory. Once the information is in memory, the impact of the original form of the information source is largely irrelevant, consistent with the assumptions of the WiTS approach and Teichner's processing model. These findings do not support the proposition that the input and output side of the task are independent. In fact, the results due to the response mapping show that quite the opposite is true.

Response Panel Mapping. The response mapping had minimal impact on performance accuracy. In fact, it only impacted performance accuracy early in practice, and again, intermittently, fairly late in practice. The effect arose because the identification of four targets with the compound response mapping was much less stable than the identification of four targets with the separate response mapping. Performance in identifying four targets with the compound response panel started off being significantly worse through the first three blocks than that for the other conditions, and then got better so that the performance was no longer significantly different. With practice, performance

accuracy again deteriorated to become significantly worse with the identification of four targets than with the separate response mapping in blocks 6 and 8 of practice, indicating sensitivity to fatigue effects with extensive blocks of practice. Unlike the accuracy data, which showed that the compound response mapping was, at least intermittently, significantly worse than the separate response mapping, the latency data showed that the compound response mapping was significantly better than the separate response mapping, particularly when compound targets were being identified. What is even more striking, is that the effects of response mapping, which would intuitively be expected to affect only the output side of the task, should have such persuasive effects on input processing. The significant main effect for response mapping on input time clearly demonstrates that the output side of the task affects input processing.

The response mapping manipulation had more of an effect on input processing than output processing as measured by input time per target and output time per target. These effects, while intuitively suspected, could not have been predicted on the basis of any empirical data prior to this research. The results show that, overall, the reading of codes from a display and encoding them into memory when identification is to take place using the separate response mapping will be slower than the identification of targets involves the use of the compound response mapping. Further, this effect disappears when separate targets are being identified, but is persistent across practice when compound targets are being identified. Further, the effect is more profound when more targets are being identified. Finally, the effects due to the type of response mapping on input time are less stable early in practice (Figure 6-14). It is possible to propose an explanation for why the compound response mapping should be faster when codes from compound targets are being identified if the task is considered in terms of S-C-R compatibility.

Wickens (1984) suggested the notion of S-C-R compatibility in order to explain why certain types of codes empirically proved to be processed more efficiently when presented and then

responded to in one modality as opposed to another. Specifically, he proposed that verbal information was more efficiently processed when it was transmitted to the person as an auditory message and responded to vocally. Spatial information was described as being more efficiently processed when presented visually and responded to manually. The important point from this idea, for the purpose of this study, is that there could be certain display and response arrangements that are more compatible with the way people think about performing a task than others, i.e. are cognitively compatible. If we extend this idea to the empirical results of this study with regard to the better response times in reading in codes from compound targets when the response panel also has a compound arrangement, as opposed to a separate arrangement, it can be argued that this is another form of cognitive compatibility. Perhaps because the person performing the task knows he will be responding using a compound response panel, he is able to process the information more efficiently as he reads the display and encodes the information into memory.

Though there were significant effects due to response mapping on output time per target, they were less extensive than might be intuitively expected. The response mapping had an impact on performance only in the context of the target density for the output time per target measure. As the target density increased, the output time per target for using the compound response mapping increased 3.25 times faster than it did when targets were identified using the separate response mapping. However, it is worth noting that early in practice this effect was moderated by the type of target being identified, suggesting that tasks which are performed intermittently, or which will be performed by inexperienced users will have different S-C-R requirements than do tasks which are performed frequently, or by users with significant experience with the task.

Blocks of Practice. Given the discussion of the results thus far, it should be clear that the blocks factor essentially had the predicted effect. Overall, the performance seen improved significantly in the first three blocks, and became stable thereafter. This was particularly the case with the latency

data which showed fairly typical learning curves. The percent correct data, as was the case in the studies described in Chapters 4 and 5, demonstrated minimal change with practice. The only effect seen was in the form of the three-way response mapping by number of targets effect due to the significantly worse accuracy for the compound response mapping when four targets were being identified during block 1 of practice. There were exceptions to the general learning trend as measured by the latency data, however. The identification of compound targets tended to result in less learning through the first three blocks than did the identification of separate targets, particularly as more and more targets were presented to be identified. In fact, the identification of four, compound targets using the compound response mapping was very atypical, with significant, intermittent decreases in performance as measured by total and input time per target as a function of blocks. These results are interpreted as showing that the blocks manipulation not only successfully allowed the assessment of learning, but also showed the sensitivity of various conditions to extended practice, or fatigue effects. Clearly, the identification of compound targets was more susceptible to practice effects, as indicated by the relative instability of performance over blocks, and thus leads to the supposition that these conditions are more difficult and demanding in terms of processing than the other conditions employed in this study.

Summary of Results

The results for each of the experiment predictions is summarized below:

1. The latency for identifying codes in the compound target-task condition proved to be 2.05 times that seen in identifying codes from the separate target-task conditions as measured by total time per target. Therefore, on the basis of total target identification time, prediction 1 is confirmed, and it can be concluded that the processing of compound targets is essentially the same as that for separate targets. The results for prediction 1 are not so clear when response time is partitioned into input and output components. The rate at which targets were read from a display and the codes encoded into memory, as measured by input time per target for compound targets, was 1.88 times that required for the separate targets. This could be interpreted as a significant departure from that stated in prediction 1. However, it was argued above that this difference was due to a net savings in visual search of more codes within foveal vision, and therefore does not reflect an effect of processing per se, and it is concluded that the basic processing of codes in separate and compound targets is the same.

2. The presence of a significant interaction between the response mapping and the target density as measured by both input time per target and output time per target supports prediction 2, and therefore it is concluded that the response mapping does affect both the way information is processed as it is encoded into memory, and the way information is removed from memory and translated into a response.

3. Stereotypic learning curves were found in much of the latency data. Further, these curves were affected by the target density where the learning appeared to extend over more blocks

when more codes were presented to be identified, and the net gain in performance with practice was greater when more targets were being identified. This supports the assertion that the identification task involves a significant component of information processing, because the conditions with a greater number of targets to be identified effectively were more complex, and required more time to learn. Together, these results support prediction 3.

Objectives

This study continues to address and extend the theoretical, methodological and application objectives of the overall research described throughout this document. The first objective was to demonstrate the utility of the WiTS methodology in terms of a) assessing performance in an identification task, and b) demonstrating the theoretical and practical implications of the impact of particular information codes and code arrangements have on information. Clearly this objective has been met. The partitioning of overall response time into input and output time components generated patterns of significant results in input time that were either 1) not detected in the total response time measure, and/or 2), that were different from each other and therefore allowed the results obtained to be explained in ways that were not possible with the overall latency measure alone. Perhaps the best example of this was with the findings with regard to the response mapping effects. No main effects were found for the response mapping manipulation as measured by total time per target and output time per target, and yet, there was a significant effect for the response mapping effect for the input time dependent measure. Thus, the partitioning of total time per target into input and output time components revealed that there were effects that typically are attributed

to the output side of the task, (i.e. response mapping), on the input side of the task that were masked in the analyses of overall response time.

Another example of how the partitioning of total response time makes it possible to speculate on the mechanisms contributing to performance is in the analysis of the results from the target-task conditions. The separation of output effects from input effects through the partitioning of response latency, and the comparison of relative performance changes through rate measures allowed the differences in the processing of codes presented in compound targets versus separate targets to be attributed to the savings in the physiological time required to move the eye between fixations. Because codes were co-located within a single fixation in the compound targets, the processing of a similar number of codes when presented in separate targets would require twice as many fixations. Thus, it was shown that the relative performance differences between the separate and compound targets could be attributed to the visual phenomena associated with reading the display rather than differences in processing per se.

The partitioning of total response time into input and output time components also made possible the assessment of the nature of processing in the translation of information from memory into a response. Both the input time data and output time data revealed significant response mapping by number of targets effects. However, the interaction for the input time data was due to the separate response mapping always being significantly faster than the compound response mapping. Further, the input time per target data increased 1.2 times faster as a function of the target density (Figure 6-13). The interaction for the output time data and the compound response mapping, however, was significantly faster when two targets were being identified, and significantly slower than the separate condition when four targets were being identified. Thus, input and output time were apparently affected by different factors. There were no significant differences between the separate and compound response mapping conditions when three targets were being identified.

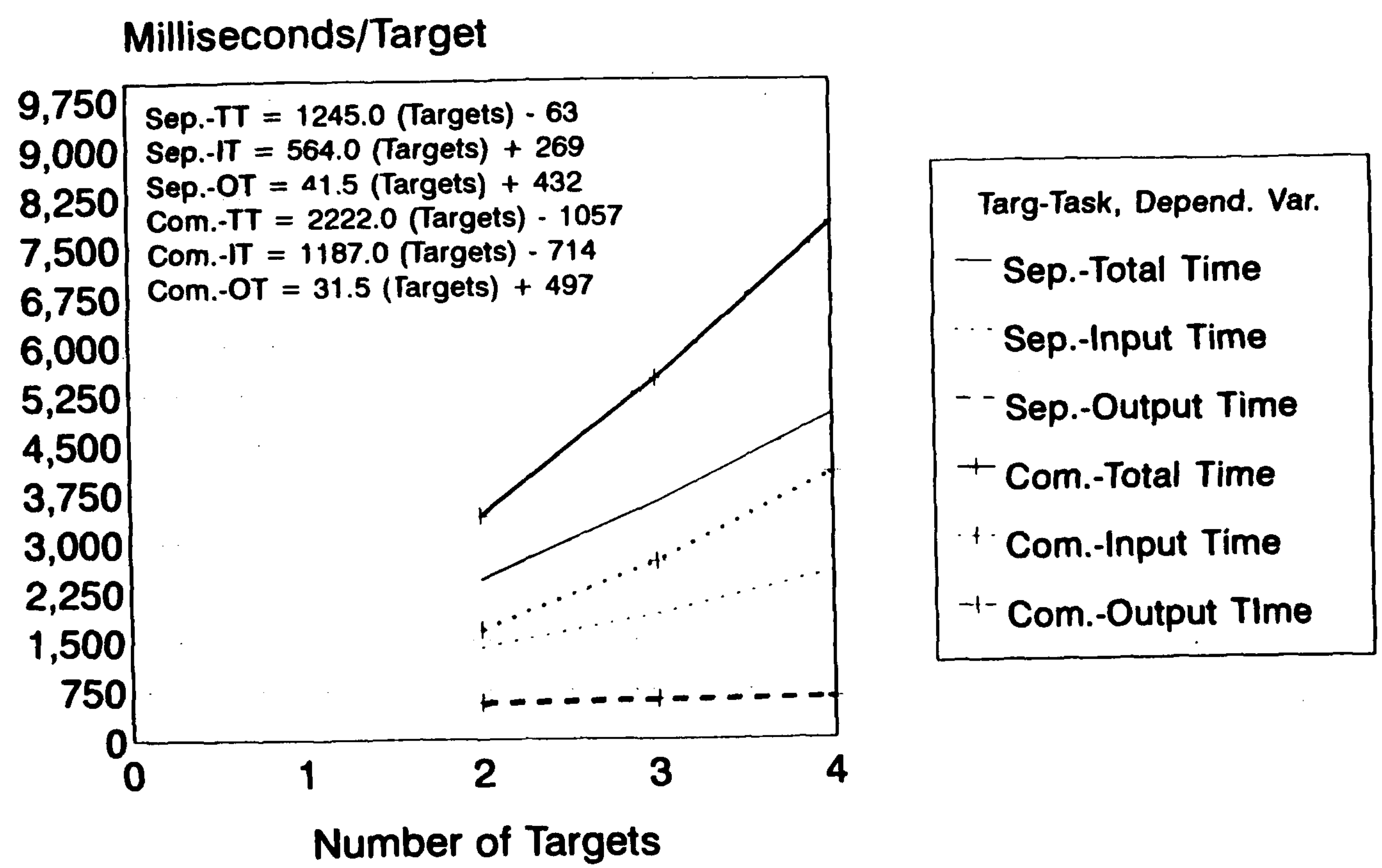
Further, the output time per target rate of increase as a function of the target density was 3.25 times that seen for the separate response mapping conditions (Figure 6-16).

The partitioning of response time into its input and output components revealed significant effects for response mapping that were not present in the total time analyses. In fact, the changes occurring in input processing and output processing effectively canceled each other so that the net changes as measured by total time per target were not detected in the total time per target measure. Clearly, the partitioning of total response time into its input and output components is appropriate for understanding the nature of performance changes and information processing in an identification task.

Objective 2 was to assess the relative changes in performance in terms of overall, input and output processing for codes which are integrated into single targets versus when the codes are presented as independent targets. The results and discussion above showed that while the rate of target identification is faster for identifying separate (single code) targets as opposed to compound (multiple code targets) the identification of codes in compound targets, when the data are adjusted for the number of codes being identified rather than the number of targets, the compound targets are in fact identified faster than the separate targets on a "per code" basis. This was interpreted as being due to the time required to locate and read single code (separate) targets when compared to multi-code targets. Thus, it is concluded that the processing associated with single as opposed to multiple code targets is essentially the same, and the difference in the rate of code identification is due to the savings in physically locating and reading fewer targets to translate the same number of codes into memory.

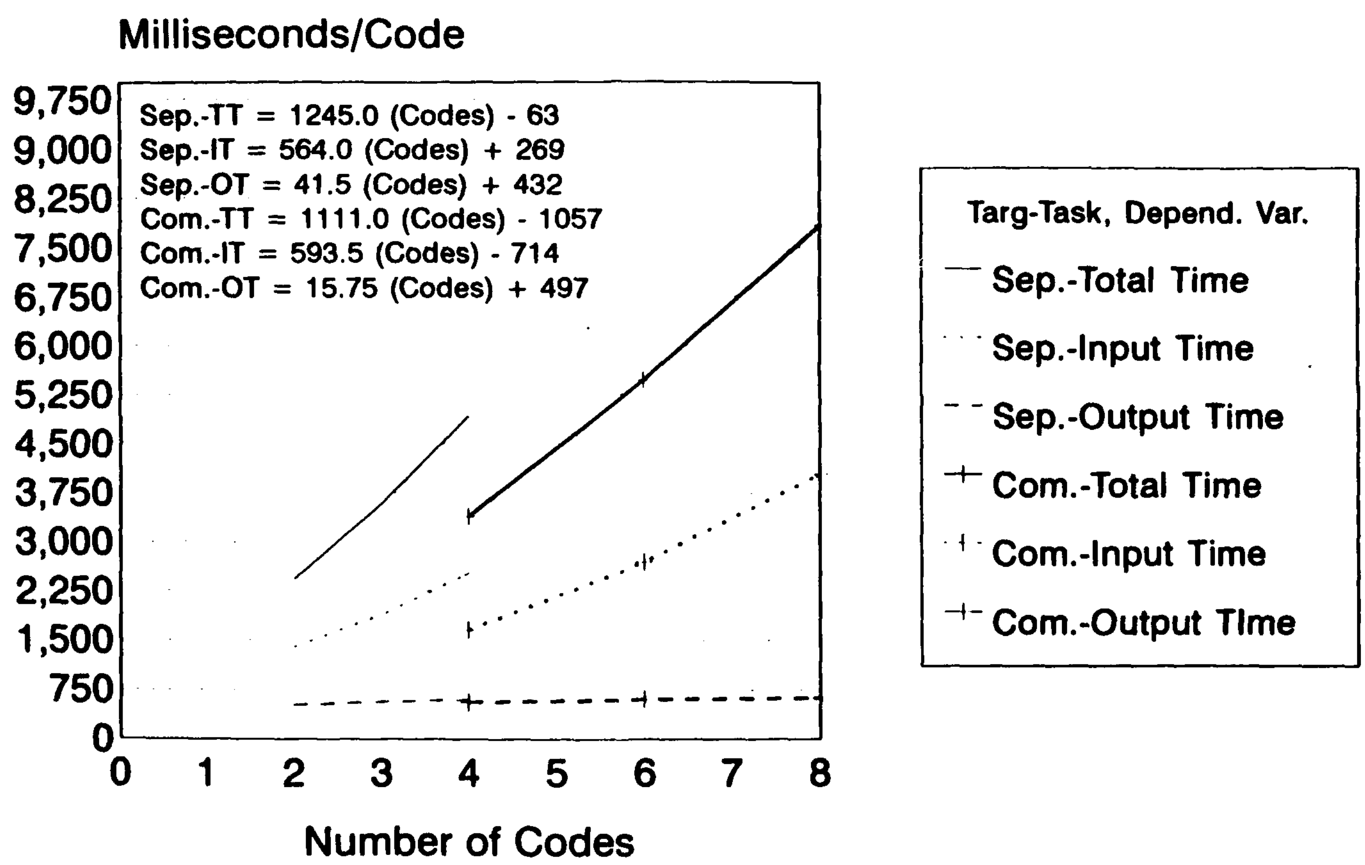
The relationship of total, input and output time as a function of the number of codes in each target is illustrated in a different context in Figure 6-18. This figure shows that there were

Figure 6-18. Separate, Compound:
Total, Input & Output Time by Number of Targets.



8 April 1992

Figure 6-19. Separate, Compound:
Total, Input & Output Time by Number of Codes.



14 April 1992

significant intercept differences for the total, and input time per target, regressions as a function of target density and the particular target-task condition being used. The output time regressions for the separate and compound target-task by target density regressions were in fact virtually identical in terms of both slope and intercept. It can therefore be concluded that the output processing is identical regardless of the type of code being read from the display. The slopes for the total and input time per target regressions were different as a function of the target density. The compound target-task condition showed a decrease in the rate of target processing that was greater than that seen for separate target-task condition. However, when plotted in terms of the number of codes processed, (Figure 6-19) the slopes of the total and input time per code regressions are effectively identical. This supports the conclusion that the processing of codes is identical in both single and multiple code targets, and any differences between the conditions is due to the physiological movement times of the eye in scanning the display for targets.

Objective three was to assess the relative impact of alternative response mappings on input and output processing. Clearly, the response mapping had impacts on input and output processing, and those effects were different for input and output. However, it is also worth emphasizing the significant interactions of the target-task manipulation and response mapping and their implications for the design of information processing tasks. The identification performance as measured by input time for compound targets was significantly enhanced by using the compound response mapping. Thus, not only were the results for the separate and compound response mappings different as measured by input and output time, but the input effect was also affected by the arrangement of codes within the targets on the display. This finding is consistent with the theoretical concept of stimulus-response compatibility, and suggests that future studies of stimulus-response compatibility would benefit from considering input and output processing and the application of the WiTS methodology.

Applications & Lessons Learned

The applications of this study are perhaps illustrated through the presentation of the results in terms of principles and guidelines. Therefore, this discussion will close with the presentation of prospective principles and guidelines for the design of information processing tasks in general, and target identification tasks in particular.

1. If accuracy is the primary concern in designing a task involving the need to read information from targets on a display, then the use of multiple-code targets where all codes are relevant to the task will greatly reduce the accuracy with which the targets are processed. This effect becomes more dramatic as the number of targets being processed is increased, such that in comparing single to dual code targets, there is a drop in accuracy of 17.5% for every additional target placed on the display to be identified.

2. If the rate of information input is the primary concern in designing a task involving reading information from targets from a display, then significant savings can be achieved by incorporating multiple codes into a single target. The effect of this coding will be to save approximately 300 milliseconds for every additional target that can be removed from the display by the alternative coding scheme. The savings reflects minimal changes in the way the information is processed, and is due to the time saved in visually locating and fixating the targets that were removed from the display by the coding scheme.

3. The response mapping employed can and will affect the way information is read from a display and encoded into memory. Further, the nature and magnitude of the effect will depend on the particular codes used, the nature of the processing task, and their relationship to the response mapping. This study shows that if all codes in the display are relevant to the task, and multiple code targets are used, then the response mapping should

have a multiple-code coding scheme similar to that used in the compound targets for the optimum overall rate of processing, and particularly the rate at which codes are read from the display and encoded into memory.

4. The use of compound response mappings causes the rate at which information is taken from memory and decoded into a response to be slower when multiple codes are assigned to each alternative response, particularly as higher numbers of response are required by the task. Therefore, tasks which employ a minimal amount of information on a display, but a proportionally large number of responses, (e.g. an information creation task, ala Briggs, 1974; Teichner & Williams, 1977), should use single code response mappings.

6. Tasks which are performed intermittently, or for which the users can be expected to have little experience, will be particularly sensitive to the effects of the number of codes in the target, and the response mapping, particularly as they read information from a display and encode it into memory. Therefore, if novice or intermittent users will be performing the task, and the task requires the reading of a large number of codes from the display, the use of multi-code targets should be avoided for optimal speed and accuracy in performing the task.

(This page intentionally left blank.)

CHAPTER 7 - Identification of Fully Redundant Codes.

This chapter describes the results from the fourth in a series of studies examining the effects of display and response codes in an identification task. It also represents the final study to be described in this report. Chapter 4 described the identification of single code targets in which the codes were from either one of two different categories of codes, or in which the codes were from both categories. The results of that study showed that 1) equivalent subsets of digit codes and letter codes were in fact processed differently in an identification task; and 2) that the identification of subsets of codes consisting of both letters and digits generated identification performance comparable to that of the worst of the component code categories as measured by accuracy, total time per target, and output time per target, but worse as measured by output time.

Chapter 5 described the second study which examined the effects due to the use of compound (two code) targets where the component codes in the target were from two different categories of codes, and only one of the codes in the target was relevant to the identification task. The results of this study showed that the presence of an irrelevant target code caused the performance as measured by accuracy to improve relative to the comparable identification task with only a single code in the target. However, this improvement came with a slight cost in terms of the rate at which compound targets were processed, particularly as higher numbers of targets were presented to be identified. The locus of the effect was shown to be input processing, as defined by Teichner's processing model and the Within-Task Subtractive (WiTS) methodology. Further, there was a time-on-task (practice) effect found for the presence of irrelevant codes when letters were

identified using a more complex (compound) type of response mapping in input time. This effect was attributed to fatigue factors induced by the complexity of this particular identification task.

The study described in Chapter 6 assessed the effects of identifying codes from multiple code categories when they were presented as either single, or multiple code targets. The results showed that the input processing of multiple codes from single targets was essentially the same as that for single code targets, because the difference in rates of processing were shown to be equal to the time required to move the eye between targets.

With regard to the effect of response mapping, the studies described in Chapters 4, 5 and 6 all showed that in one way or another, the response side of the task affected both input and output processing, and the effects on input and output processing could be different from each other. In summary, the results of Chapters 4, 5 and 6 show that the way information is processed in an identification task is a function of: 1) the particular codes being used, 2) how those codes are arranged on the display, 3) the particular nature of the response required, and finally, 4) the particular instructions given to the subject as to how to perform the task.

The redundant target-task conditions which are the focus of this chapter are very similar to the compound target-task conditions described in Chapter 6. Targets consisting of two codes, one being a letter and the other being a digit, were presented to subjects. Subjects were instructed to identify both codes in each target, as they were with the compound target-task condition. However, in the redundant target-task condition, there was an additional property to the codes used in that the same letter always appeared with the same digit, i.e. the letters and digits were fully redundant. In theory, the effect of using a fully redundant code should be minimal because, by definition, the redundant code carries no additional information, (Attneave, 1954; Garner, 1962). However, there is no empirical data on the effects of code redundancy on input and output processing. Therefore, the

question being investigated is: How are the fully redundant codes processed relative to the processing of non-redundant or irrelevant codes?

The objectives of this study are essentially the same as those in Chapter 4, 5 & 6. They are:

1. Apply the Within-Task Subtractive methodology for response time partitioning to the study of redundant information codes and discuss the results in the context of a) performance in a target identification task, and b) assessing the theoretical and practical implications of the results found.

2. Assess the relative performance of identifying codes in targets in which the codes are redundant, the codes are both different and relevant, or the codes are different and one of them is irrelevant.

Morrison, Corso & Yuasa have addressed the question of redundancy to some degree in the context of the WiTS methodology. They assessed targets in which color and semantic (name) coding were fully redundant. Their first experiment used four colors (red, green, yellow and blue) and the four corresponding color names ("RED", "GREEN", "YELLOW" and "BLUE") as stimuli. Their second experiment used the same four colors, and animal names ("BEAR", "MOUSE", "LION" and "DONKEY") as the stimuli. Three conditions were used in each experiment. The color condition used only blocks of the appropriate hue as stimuli. The names condition used only the hue or animal names as stimuli. Finally, the redundant condition had the hue or animal names consistently printed in the same color, in the case of color names the color used corresponded to the color name, e.g "RED" printed in red. Thus, the names and colors were fully redundant. The results showed that code redundancy did affect performance in an identification task, but only when large numbers of stimuli were presented to be identified. The nature of the effect was to improve identification accuracy. With regard to the rate of target identification, the performance improved with redundant

coding to be as good as that for the more quickly identified of the component codes with relatively large numbers of codes. However, when only two targets were identified, their results showed that the response time performance with the redundant coding condition was a composite of that seen with the two single code conditions, i.e. the mean of the latency seen with the name condition and the color condition. Further, examining the rate of input and rate of output as defined by the WiTS procedure used in this research, the locus of the redundancy effect was shown to be in input processing.

While Morrison, Corso & Yuasa were able to demonstrate that coding redundancy did affect performance in an identification task, and that the locus of that effect was in input processing, they were not able to make attributions as to how those codes were processed. For instance, it has been suggested that hue and semantic codes are processed in parallel, and therefore the effects seen in Morrison, Corso & Yuasa could be attributed to the combined benefits of processing both codes together, or due to simply processing the more efficient of the component codes. Similar results were obtained by Rudolph (1992) in his study using redundant spatial and numeric coding. This study will avoid the issue of parallel processing mechanisms by using stimulus codes that are selected from the same categories, and therefore, the discussion of performance differences due to redundancy can avoid the issues associated with the processing mechanisms of the two codes. Further, appropriate control conditions will be used so that the effects of redundant code symbols may be compared to the processing of equivalent non-redundant code symbols, and the selective processing of codes within a target.

DESIGN

This study will utilize three of the target-task conditions described in Chapter 3. The experimental design, shown in Figure 7-1, shows that three factors were manipulated in this study. The first factor is referred to as the target-task. The targets used in all the target-task conditions used in this study will employ targets consisting of a digit and a letter. However, relevance of the codes within each target and the relationship of the codes within each target will differ. With the compound (letters) target-task condition, an unrelated digit and letter code were presented within each target, however, the subject was instructed to identify only the letter code, and the digit code effectively served as noise[18]. In the compound target-task condition, an unrelated digit and letter code is presented in each target, and the subject was to identify both codes in every target. In the redundant target-task condition, a digit and letter code were presented in each target and both codes were to be identified, however the same letter code always appeared with the same digit code. The second manipulation, display density, referred to whether two, three or four targets were presented in the 4 by 4 cell matrix on the display.

On an intuitive basis, it can be speculated that the compound (letters) and compound target-task conditions should represent two ends of a task demand spectrum. The compound (letters) target-task condition should be relatively easy because only a single code within each target is relative to the identification task. The compound target-task condition should be relatively difficult because there are more codes to identify per target, and the codes come from different

[18]The compound (letters) condition was chosen as the comparison condition for this study based on the results of the study described in Chapter 5. One conclusion reached in Chapter 5 was that the compound (letters) condition was cognitively more complex than the compound (digits), and that the digits and compound (digits) may generate different processing than do letters and conditions in which both digits and letters are being processed. Therefore, the compound (letters) condition was chosen as a control for this study because there is no a priori reason to expect that processing was somehow qualitatively different would be different from the other conditions used in this study.

Figure 7-1. Experimental Design for the Compound (Letters), Compound, Redundant Comparison.

	Target -Task Type	Response Mapping	Within Factors Number of Targets:	2	3	4
			Blocks:	1-10	1-10	1-10
Between Factors	Compound (Letters)	Compound				
	Compound	Compound				
	Redundant	Compound				

categories. The redundant target-task condition should fall somewhere in between these two extremes. Early in the identification of the redundant targets, the task may appear to the subject to be as demanding as the compound target-task condition, because both codes within each target will have to be read and encoded into memory[19]. However, very rapidly the relationship between the two codes in the redundant targets will become apparent, and the subject may adopt different strategies in identifying redundant targets. For instance, one or the other code in each target could be effectively ignored when reading targets from the display and encoding them into memory, or the two codes could come to be seen as a single composite code. If this happens, the input time per target performance with the redundant target-task condition will rapidly come to resemble that seen with the compound (letters) condition as a function of practice. If, however, the redundant codes can not be, or are not, ignored, then the performance with the redundant target-task conditions will still improve dramatically relative to the performance seen in the compound target-task conditions, however it will never reach the same level of performance seen with the compound (letters) conditions.

The rationale for input time described above will probably be appropriate to some degree for total time per target because input time accounts for such a large proportion of total time per target. Output time per target, however, can be intuitively expected to show markedly different performance as a function of target-task condition. Since the particular response mapping used in this study will be: A1, B2, C3, D4, E5, F6, G7 and H8, (or in the counterbalanced conditions: 1A, 2B, 3C, 4D, 5E, 6F, 7G and 8H); and the redundant target mappings were identical, the identification of the second code in each redundant target requires only that each response button be

[19]In the course of the subject briefing, subjects were informed as to the nature of any relationship among the codes in each target, i.e. they were informed that they would see a digit and a letter code (or letter and digit code in the counter-balanced conditions) and that they would either 1) see different digit-letter combinations, or in the redundant case 2) see the same digit with the same letter. The net effect of this instruction was that subjects were aware of the fully redundant codes at the start of each redundant session. For more information on the procedure, see Chapter 3.

pressed twice. This will have the effect of reducing the response selection component of the output processing by half because only half the codes need to be processed in order to respond correctly relative to the output processing required for the compound, and compound (letters) target-task conditions. Therefore, the rate of output processing for the redundant target-task condition should be approximately twice for the non-redundant target-task conditions.

The additional factors manipulated in this study, (shown in Figure 7-1), were the number of targets that are presented to be identified (i.e. target density), and the number of blocks of practice. Both of these were within-subjects factors. The target-task manipulation was a between-subjects factor. The response mapping for this analysis was not manipulated, only the compound response mapping is used. The resulting experimental design was a 3 by 3 by 10 split-plot factorial design. Additional information regarding the specific targets used, the counter-balancing of codes within targets, the details of the compound response mapping, the display, apparatus and general procedure may be found in Chapter 3.

With the conceptual discussion of the redundant target-task condition and its processing relative to the compound and compound (letters) target-task conditions, it is now possible to present several formal predictions for this study.

1. If the input time per target performance seen from the redundant conditions is comparable to that seen for the compound target-task conditions early in practice, and comparable to that seen for the compound (letters) target-task conditions in later blocks, then it can be concluded that the both codes in the redundant targets are being processed when the task is being learned, and that when subjects realize that the redundant codes carry no informational value, they come to be ignored. However, if the performance seen with the redundant codes is significantly different from the compound (letters) target-task conditions

later in practice, then it must be concluded that the redundant codes are processed differently than the irrelevant (i.e. noise) codes, despite their having no formal informational value.

2. If the rate of output processing for the redundant target-task conditions is approximately half that seen for the compound and compound (letter) conditions then only the one of the redundant codes in each target are being processed during output.

RESULTS

The comparison of the compound (Letters), compound and redundant target-task conditions was performed through a series multi-variate analysis of variance (MANOVA) procedures. All MANOVAs were performed using the Complete Statistical Software (CSS: Statistica) analysis package for MS-DOS computers (Statsoft, 1991). Post-hoc comparisons for significant effects were performed using the Neuman-Keuls procedure (Kirk, 1982; Statsoft, 1991) included as part of this statistical software[20]. A separate MANOVA was performed for each of the dependent variables: Percent Correct, Total Time per target, Input Time per target, and Output Time per target. The results of these analyses are summarized in Table 7-1 and are described in detail below. Based on the results for practice described in Chapters 4, 5 and 6, and the finding of significant learning effects during the first three blocks, additional analyses were performed on the data obtained from blocks 1-3 as well as from blocks 4-10. These analyses are summarized in Table 7-2 and Table 7-3. The results for all the dependent variables are discussed below.

Percent Correct. Figure 7-2 reflects all the effects for the analysis of percent correct data that proved significant from all blocks of practice. There was a significant three-way interaction for the target-task conditions, target density and blocks, ($F = 1.50$, (36,324), $p < .05$). The effect arose because the identification of four, compound or redundant targets was significantly less accurate than the identification of four compound (letter) targets in blocks 1 and 2 of practice. Over all blocks of practice, the compound and redundant target-task conditions did not prove significantly different

[20]It should be noted that there were a significant number of missing cells in the analyses involving the compound target-task condition due to subjects failing to accurately identify any targets in one of the within-cells conditions. This missing data required procedures to be used in the analyses that adjust for an unbalanced design. As part of its procedure, CSS:Statistica drops subjects with an excessive amount of missing data so that the resulting matrices are not singular. The means reported in this Chapter will reflect the means used by CSS:Statistica after adjusting for unbalanced design.

Table 7-1. Summary of MANOVA results for Compound (Letters), Compound, Redundant.[57] [58] [59]

EFFECT:	% CORRECT:	TOTAL TIME:	INPUT TIME:	OUTPUT TIME:
Condition (C)	$F = 14.7, (2,18)$ $p < .01$	$F = 29.8, (2,18)$ $p < .01$	$F = 10.1, (2,18)$ $p < .01$	$F = 22.9, (2,18)$ $p < .01$
Targets (T)	$F = 44.5, (2,36)$ $p < .01$	$F = 185, (2,36)$ $p < .01$	$F = 244, (2,36)$ $p < .01$	$F = 17.0, (2,36)$ $p < .01$
C_T	$F = 15.1, (4,36)$ $p < .01$	$F = 12.8, (4,36)$ $p < .01$	$F = 9.99, (4,36)$ $p < .01$	$F = 1.65, (4,36)$ $p = .182$
Block (B)	$F = 1.55, (9,162)$ $p = .136$	$F = 2.80, (9,162)$ $p = .072$	$F = 5.07, (9,162)$ $p < .01$	$F = 13.76, (9,162)$ $p < .01$
C_B	$F = 1.80, (18,162)$ $p < .05$	$F = 2.64, (18,162)$ $p < .05$	$F = 3.29, (18,162)$ $p < .01$	$F = 0.61, (18,162)$ $p = .887$
T_B	$F = 2.52, (18,324)$ $p < .01$	$F = 1.63, (18,324)$ $p = .175$	$F = 1.80, (18,324)$ $p < .05$	$F = 1.21, (18,324)$ $p = .252$
C_T_B	$F = 1.50, (36,324)$ $p < .05$	$F = 2.27, (36,324)$ $p < .05$	$F = 1.57, (36,324)$ $p < .05$	$F = 1.48, (36,324)$ $p < .05$

[57]Condition (C) refers to the target-task conditions used in this analysis. Response (R) refers to the response panel mapping effect. Targets (T) refers to the number of targets being identified. Block (B) refers to the number of blocks of practice. Interaction effects are denoted by the abbreviation for the effects separated by an underscore, e.g. C_R indicates the Condition by Response mapping interaction.

[58]Analysis uses {Compound-Letters-Compound, Compound-Both-Compound, Redundant-Both-Compound} as groups.

[59]Table based on analyses of April 17, 1992.

Table 7-2. Summary of MANOVA results for Compound (Letters), Compound, Redundant, Blocks 1-3 of Practice.[60] [61] [62]

EFFECT:	% CORRECT:	TOTAL TIME:	INPUT TIME:	OUTPUT TIME:
Condition (C)	$\underline{F}=15.0,(2,20)$ $p < .01$	$\underline{F}=33.5,(2,20)$ $p < .01$	$\underline{F}=11.2,(2,20)$ $p < .01$	$\underline{F}=21.7,(2,20)$ $p < .01$
Targets (T)	$\underline{F}=28.7,(2,40)$ $p < .01$	$\underline{F}=493,(2,40)$ $p < .01$	$\underline{F}=115,(2,40)$ $p < .01$	$\underline{F}=4.55,(2,40)$ $p < .05$
C_T	$\underline{F}=7.87,(4,40)$ $p < .01$	$\underline{F}=24.6,(4,40)$ $p < .01$	$\underline{F}=8.26,(4,40)$ $p < .01$	$\underline{F}=2.59,(4,40)$ $p = .051$
Block (B)	$\underline{F}=0.86,(2,40)$ $p = .433$	$\underline{F}=11.2,(2,40)$ $p < .01$	$\underline{F}=0.68,(2,40)$ $p = .514$	$\underline{F}=12.2,(2,40)$ $p < .01$
C_B	$\underline{F}=1.28,(4,40)$ $p = .292$	$\underline{F}=2.80,(4,40)$ $p < .01$	$\underline{F}=2.94,(4,40)$ $p < .05$	$\underline{F}=1.13,(4,40)$ $p = .356$
T_B	$\underline{F}=1.33,(4,80)$ $p = .266$	$\underline{F}=2.60,(4,80)$ $p < .01$	$\underline{F}=2.12,(4,80)$ $p = .086$	$\underline{F}=0.46,(4,80)$ $p = .762$
C_T_B	$\underline{F}=1.63,(8,80)$ $p = .131$	$\underline{F}=2.50,(8,80)$ $p < .01$	$\underline{F}=1.89,(8,80)$ $p = .073$	$\underline{F}=1.18,(8,80)$ $p = .321$

[60] Condition (C) refers to the target-task conditions used in this analysis. Response (R) refers to the response panel mapping effect. Targets (T) refers to the number of targets being identified. Block (B) refers to the number of blocks of practice. Interaction effects are denoted by the abbreviation for the effects separated by an underscore, e.g. C_R indicates the Condition by Response mapping interaction.

[61] Analysis uses {Compound-Letters-Compound, Compound-Both-Compound, Redundant-Both-Compound} as groups.

[62] Table based on analyses of April 17, 1992.

Table 7-3. Summary of MANOVA results for Compound (Letters), Compound, Redundant, Blocks 4-10 of Practice.[63 64 65]

EFFECT:	% CORRECT:	TOTAL TIME:	INPUT TIME:	OUTPUT TIME:
Condition (C)	$F=19.6,(2,22)$ $p < .01$	$F=59.1,(2,22)$ $p < .01$	$F=23.8,(2,22)$ $p < .01$	$F=36.0,(2,22)$ $p < .01$
Targets (T)	$F=32.8,(2,44)$ $p < .01$	$F=454,(2,44)$ $p < .01$	$F=270,(2,44)$ $p < .01$	$F=28.8,(2,44)$ $p < .01$
C_T	$F=18.3,(4,44)$ $p < .01$	$F=40.8,(4,44)$ $p < .01$	$F=25.4,(4,44)$ $p < .01$	$F=1.33,(4,44)$ $p = .274$
Block (B)	$F=0.95,(6,132)$ $p = .460$	$F=2.87,(6,132)$ $p < .05$	$F=1.13,(6,132)$ $p = .344$	$F=2.67,(6,132)$ $p < .05$
C_B	$F=1.52,(12,132)$ $p = .123$	$F=1.16,(12,132)$ $p = .319$	$F=0.99,(12,132)$ $p = .461$	$F=1.11,(12,132)$ $p = .356$
T_B	$F=0.64,(12,264)$ $p = .809$	$F=1.38,(12,264)$ $p = .177$	$F=0.90,(12,264)$ $p = .542$	$F=0.84,(12,264)$ $p = .604$
C_T_B	$F=1.27,(24,264)$ $p = .184$	$F=0.60,(24,264)$ $p = .930$	$F=0.87,(24,264)$ $p = .637$	$F=0.72,(24,264)$ $p = .826$

[63]Condition (C) refers to the target-task conditions used in this analysis. Response (R) refers to the response panel mapping effect. Targets (T) refers to the number of targets being identified. Block (B) refers to the number of blocks of practice. Interaction effects are denoted by the abbreviation for the effects separated by an underscore, e.g. C_R indicates the Condition by Response mapping interaction.

[64] Analysis uses {Compound-Letters-Compound, Compound-Both-Compound, Redundant-Both-Compound} as groups.

[65]Table based on analyses of April 17, 1992.

Figure 7-2. Compound (Letter), Compound, Redundant: Percent Correct

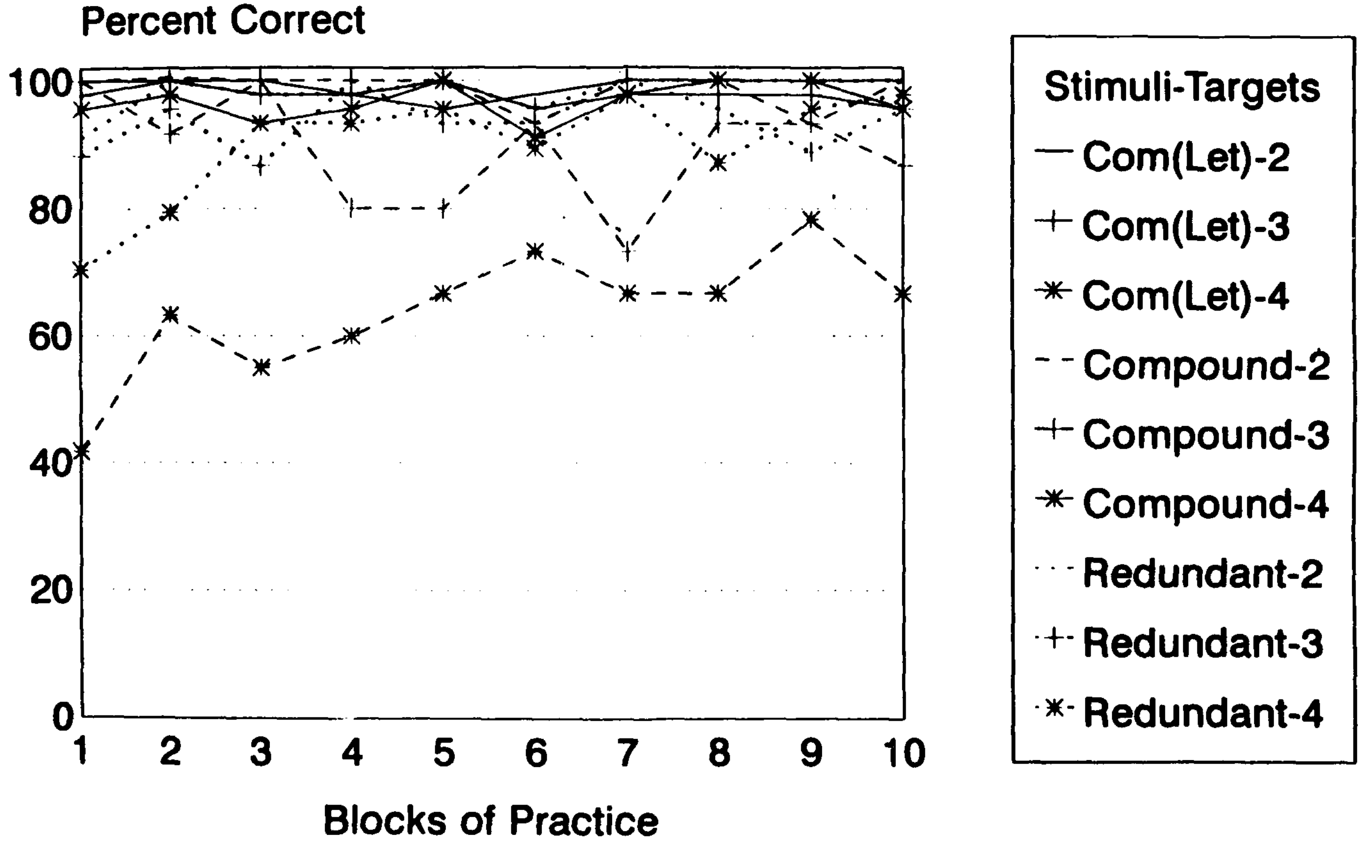
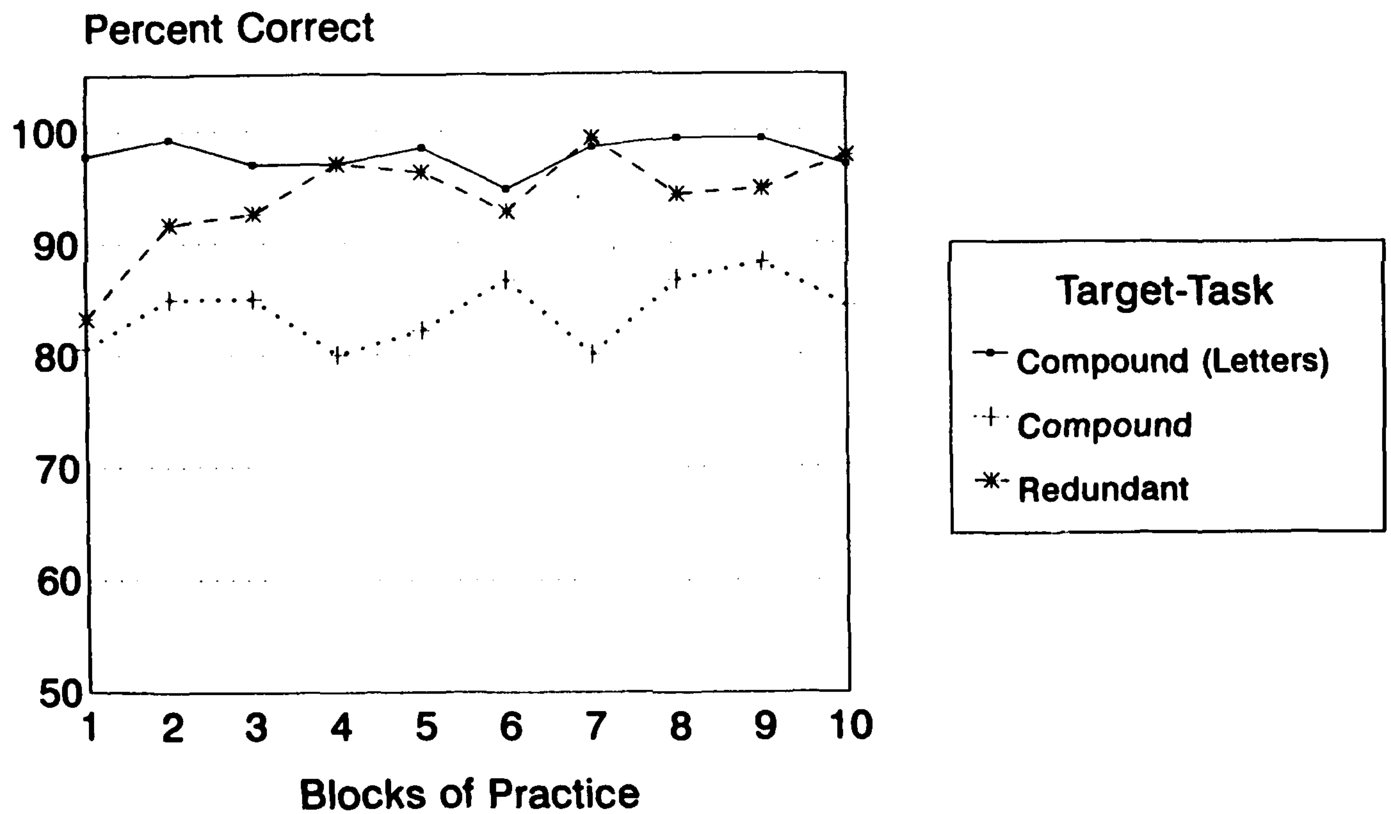
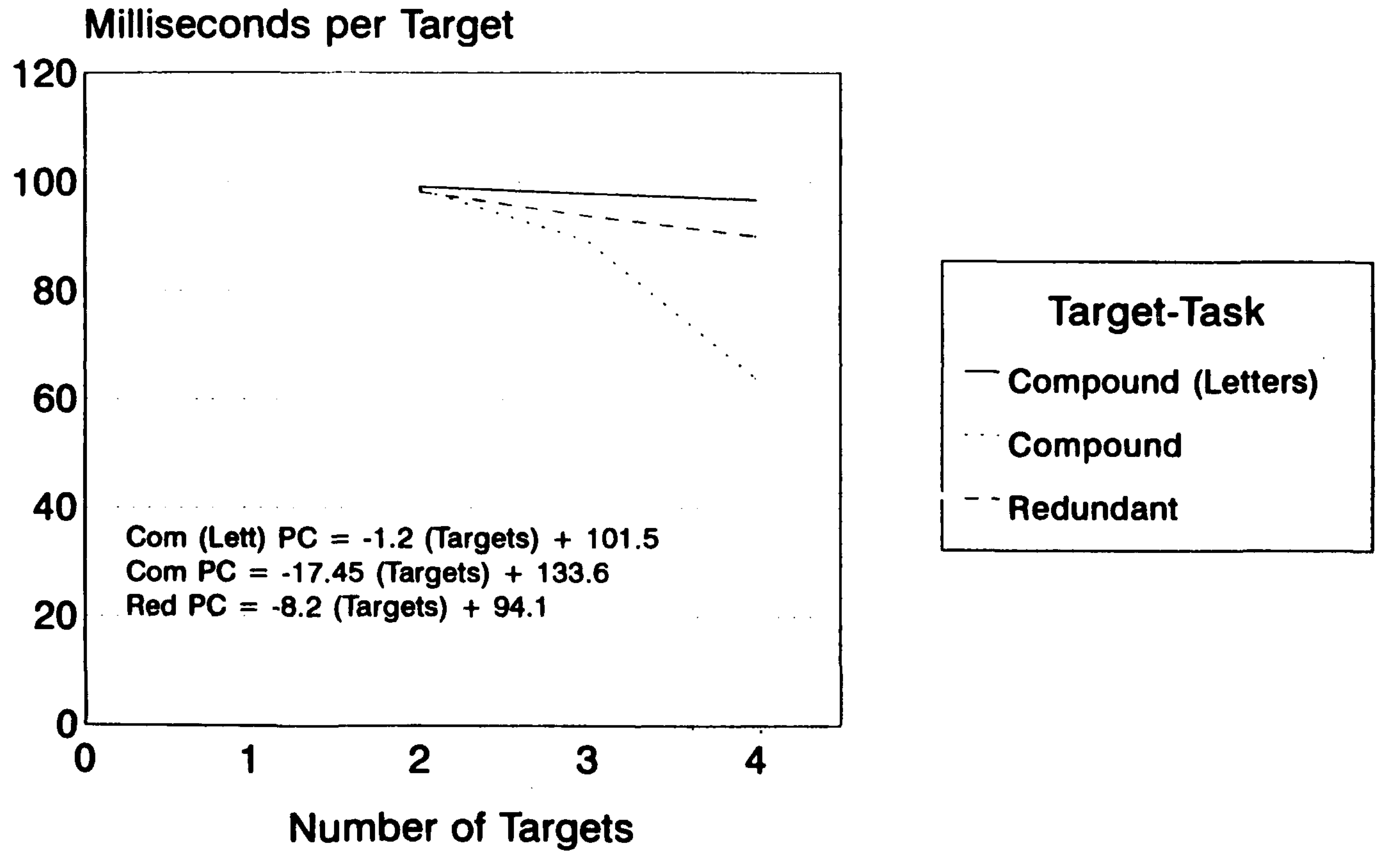


Figure 7-3. Compound (Letters), Compound, Redundant: Percent Correct - Blocks 1-10 Interaction for Target-Task Comparison by Blocks



20 April 1992

Figure 7-4. Compound (Letters), Compound, Redundant:
Percent Correct - Target-Task by Number of Targets Interaction.



20 April 1992

from each other and, in blocks 4-10, neither was significantly different from the compound (letters) target-task condition. In all blocks, the identification of four compound targets was performed less accurately than the identification of four compound (letter) or redundant targets, and in fact was significantly less accurate than the identification of two or three targets of any type. The significant three-way interaction was also brought about in part by the conditions where three redundant targets were identified being significantly less accurate in blocks 4, 5 and 7 of practice than any of the other target-task conditions when three targets were being identified.

As might be expected given the significant three-way interaction, there were also several significant two-way interaction effects in the percent correct data over all blocks. The target density by blocks interaction effect was significant due to the conditions with more targets improving more with practice than the conditions with fewer targets, ($\underline{F}$=2.52, (18,324), $p < .01$). The significant target-task by blocks effect (Figure 7-3; $\underline{F}$=1.80, (18,162), $p < .05$), was due to the redundant target-task conditions improving significantly in accuracy over blocks 1-4 of practice, while the compound (letters) and compound target-task conditions were relatively stable overall. Specifically, the compound (letters) target-task condition was different from the compound target-task condition across all blocks, while the redundant target-task condition was not significantly different from the compound target-task conditions in block 1 of practice, was different from <u>both</u> the compound (letter) and compound target-task conditions in blocks 2 and 3 of practice, and was not different from the compound (letters) condition in blocks 4-10 of practice. The target-task by target density interaction, ($\underline{F}$=15.1, (4,36), $p < .01$). was due to the accuracy of the compound and redundant target-task conditions dropping much faster as the target density increased than did the compound (letters) target-task conditions. In particular, the compound target-task condition was significantly less accurate when three targets were being identified than the compound (letters) and redundant conditions, which were not statistically different from each other. When four targets were identified, the compound target-task condition was significantly less accurate than the redundant target-task

condition, which was in turn significantly worse than the compound (letters) target-task condition. Accuracy decreased as the target density increased. This decrease is described by the following regressions:

$$\text{Percent Correct}_{\text{Compound (Letters)}} = -1.2 \text{ (Number of Targets)} + 101.5,$$

$$\text{Percent Correct}_{\text{Compound}} = -17.45 \text{ (Number of Targets)} + 133.6, \text{ and}$$

$$\text{Percent Correct}_{\text{Redundant}} = -8.2 \text{ (Number of Targets)} + 94.1.$$

Two main effects for the analysis of percent correct data for blocks 1-10 were significant. The target-task effect was due to the compound target-task conditions (83.9%) being significantly worse than the redundant conditions (94.0%) which was in turn significantly worse than the compound (letters) conditions (97.9%), (F=14.7, (2,18), $p < .01$). Finally, the target density effect was also significant, (F=44.5, (2,36), $p < .01$), with all three levels of the factor being significantly different from each other, (98.7%, 93.6% and 83.5% for the 2, 3 and 4 targets conditions).

The analysis for blocks 1-3 eliminated all but one of the interaction effects for the percent correct data. The target-task conditions by target density interaction remained significant in blocks 1-3, (F=7.87, (4,40), $p < .01$). The pattern of significant differences were the same as were described above. Target-task conditions and target density main effects remained significant (F=15.0, (2,20), $p < .01$, and F=28.7, (2,40), $p < .01$, respectively). Again, all three target-task conditions were significantly different from each other (98.0%, 74.4% and 89.2% for the compound (letters), compound and redundant target-task conditions) and all three levels of target density were significantly different from each other over blocks 1-3 of practice, (96.5%, 89.9% and 75.2% for 2, 3 and 4 targets).

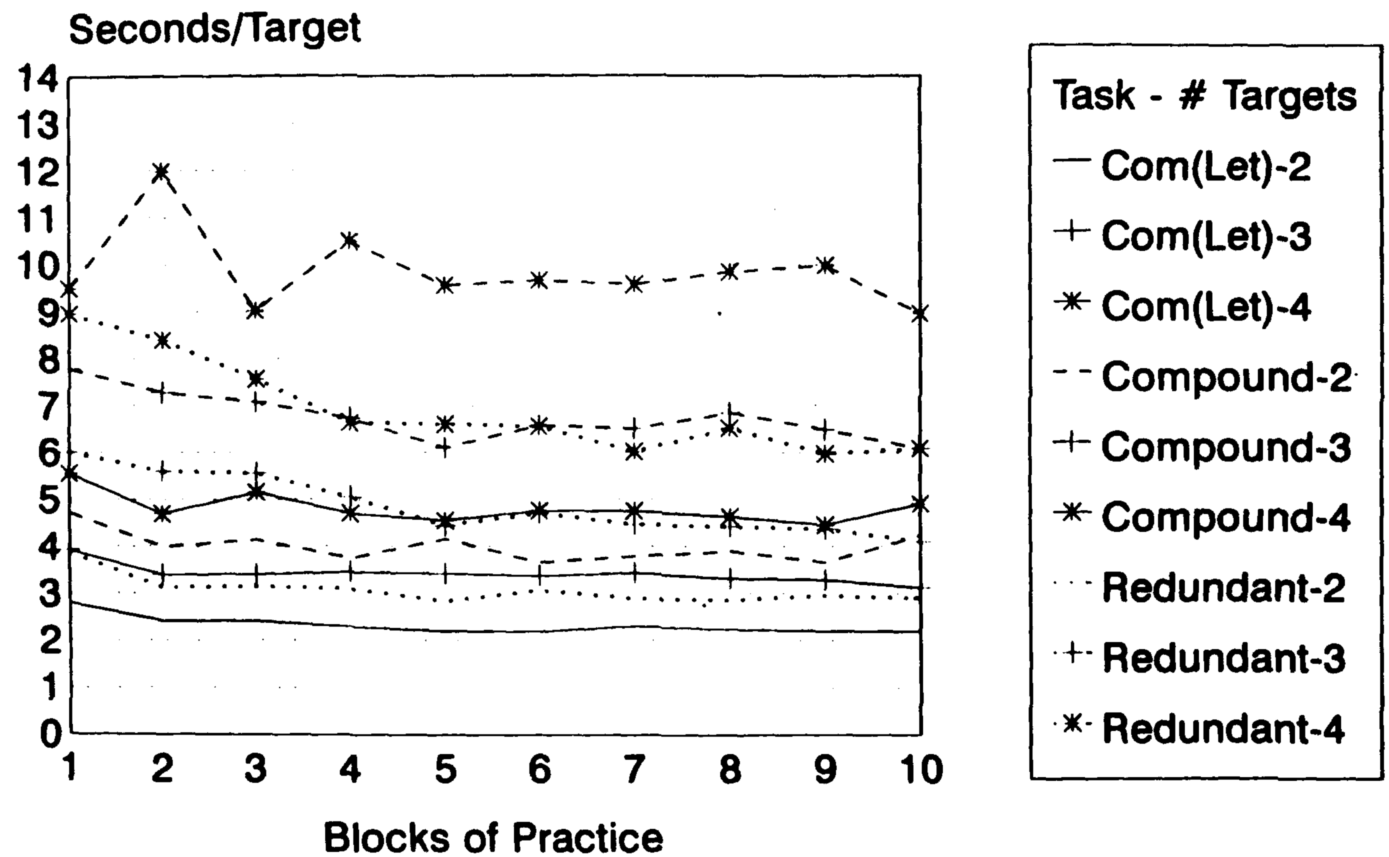
The target-task conditions by target density interaction effect was significant, (F=18.3, (4,44), $p < .01$), and once again the effect was identical to that described for the overall analysis.

The compound (letters), compound, redundant target-task conditions was significant with all three conditions being significantly different from each other (97.8%, 82.0% and 96.0% correct for the three conditions respectively, $\underline{F} = 19.6$, (2,22), $p < .01$). Finally, the identification accuracy dropped significantly as the target density increased in blocks 4-10 of practice, (98.4%, 92.9% and 84.4% for the 2, 3 and 4 targets conditions, $\underline{F} = 18.3$, (4,44), $p < .01$).

Total Time. A significant three-way interaction between the target-task conditions, target density and blocks of practice over blocks 1-10 was found, ($\underline{F} = 1.50$, (36,324), $p < .05$). This effect, shown in Figure 7-5, was due to a variety of factors. First, when the target density was two, there was no significant difference between the target-task conditions across blocks 1-10, however there were significant differences when the target density was three or four targets. When three targets were being identified, the compound (letters) target-task condition was identified significantly faster than the redundant target-task conditions, which was significantly faster than the compound target-task condition in blocks 1-3 of practice. In blocks 4-10 of practice, the redundant and compound (letters) conditions were not significantly different from each other. For four targets, the compound (letters) target-task condition was identified significantly faster than the redundant or compound target-task conditions in the first block of practice, while the compound and redundant target-task conditions were not significantly different from each other. In blocks 2-9 the redundant target-task condition was significantly faster than the compound target-task condition, and significantly slower than the compound (letters) target-task condition. In block 10 of practice, the compound target-task condition was significantly slower than the redundant or compound (letters) target-task conditions, which were not different from each other.

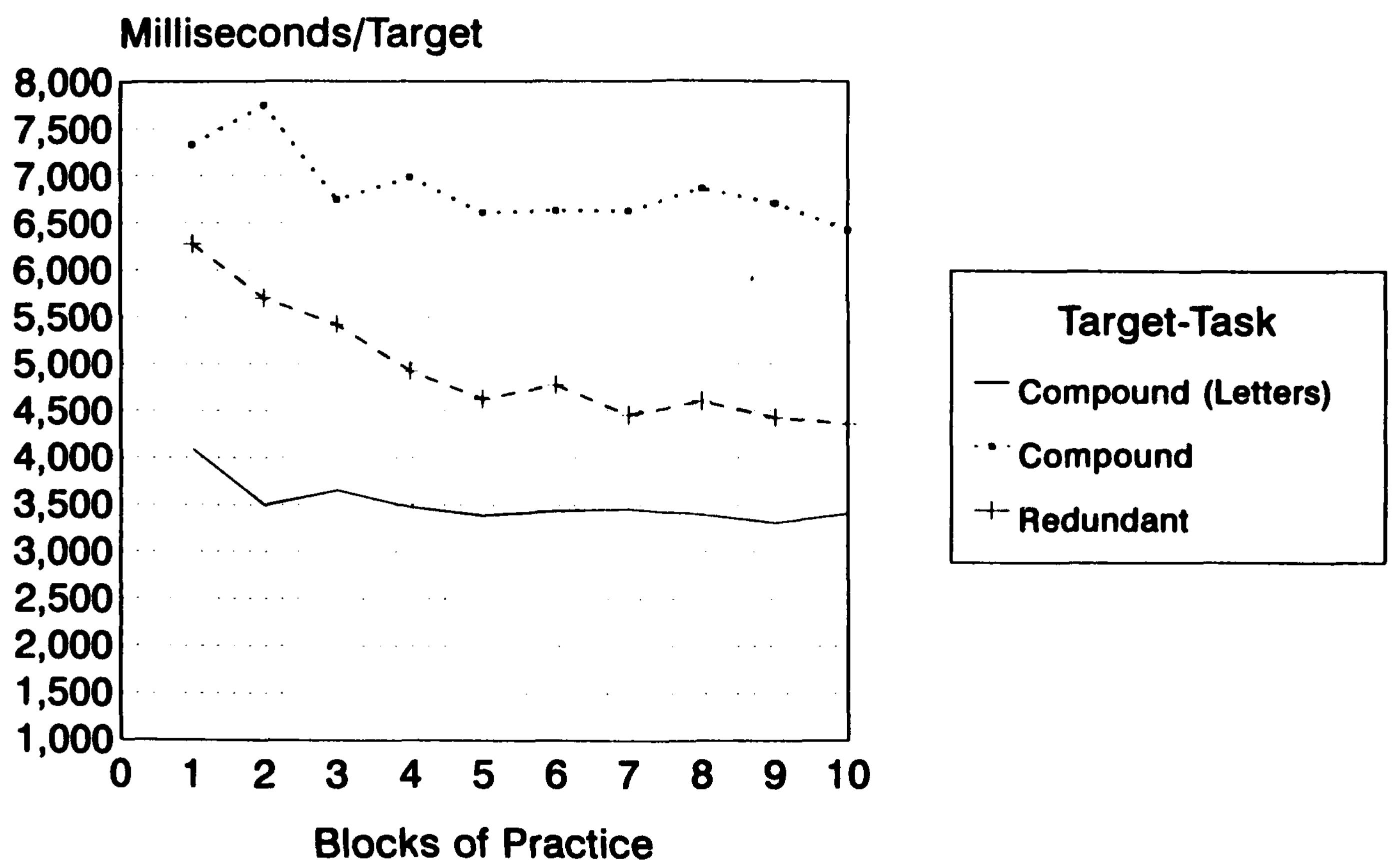
Figure 7-6 illustrates the significant target-task by blocks interaction, ($\underline{F} = 2.52$, (18,324), $p < .01$). A greater drop in total time per target with practice for the redundant target-task condition was observed than foı the compound or compound (letters) target-task conditions. The

Figure 7-5. Compound (Letters), Compound, Redundant:
Total Time



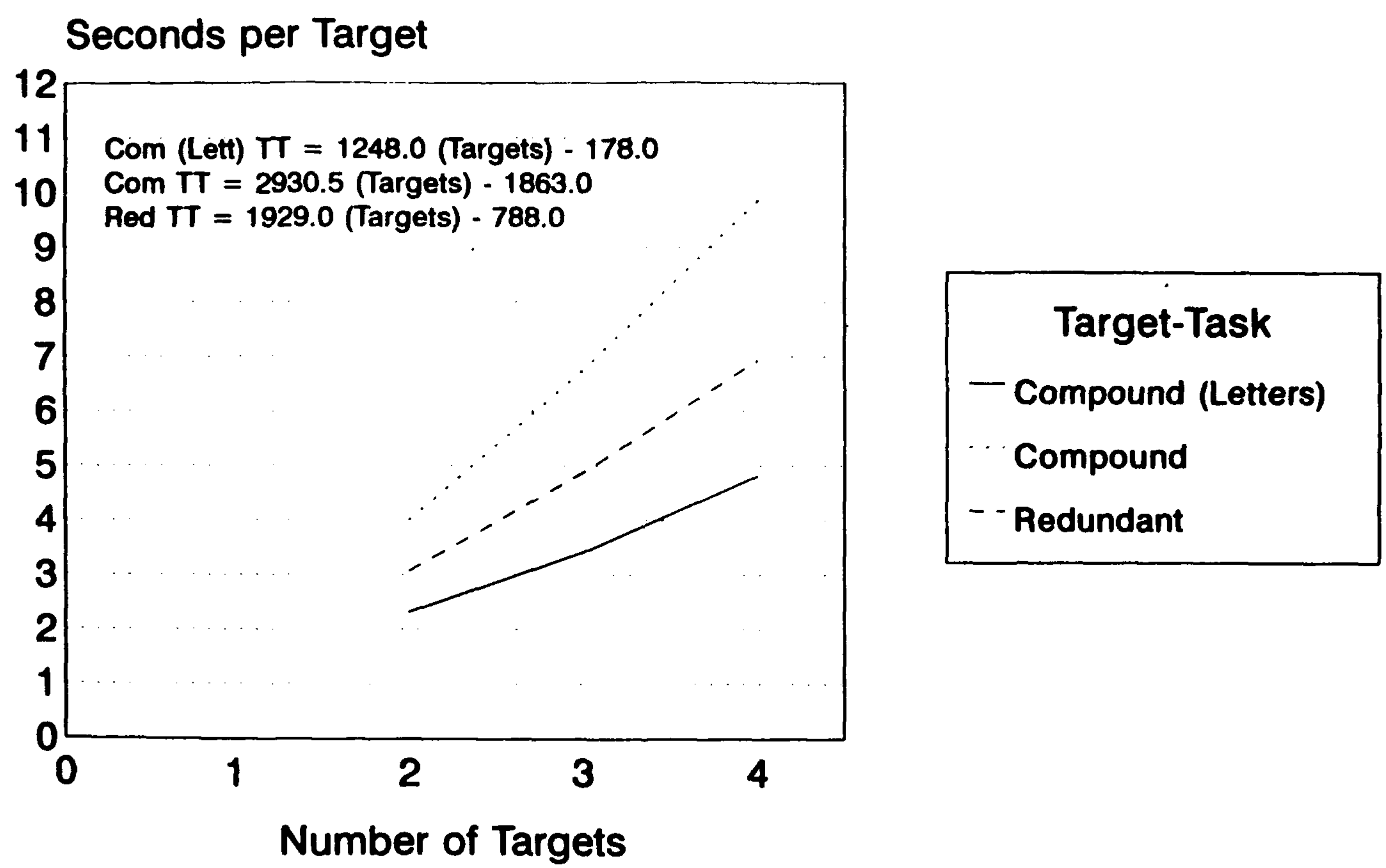
30 July 1992

Figure 7-6. Compound (Letters), Compound, Redundant: Total Time Target-Task by Blocks of Practice Interaction.



30 July 1992

Figure 7-7. Compound (Letters), Compound, Redundant:
Total Time - Target-Task by Number of Targets Interaction.



20 April 1992

significant target-task by target density interaction, ($\underline{F}$=15.1, (4,36), $p < .01$), is shown in Figure 7-7. All three target-task conditions were significantly different from each other at each level of target density. However, the magnitude of the difference increased as the target density increased. The rate of increase for the compound target-task condition was 2.35 times that for the compound (letters) condition, while the rate of increase of the redundant target-task condition was 1.55 times that for the compound (letters) condition. The interaction is described by the regressions:

$$\text{Total Time}_{\text{Compound (Letters)}} = 1248.0 \text{ (Number of Targets)} - 178.0,$$

$$\text{Total Time}_{\text{Compound}} = 2930.5 \text{ (Number of Targets)} - 1863.0,$$

$$\text{Total Time}_{\text{Redundant}} = 1929.0 \text{ (Number of Targets)} - 788.0.$$

There were two significant main effects. The target-task conditions were significant due to all three target-task conditions being significantly different from each other, (3515, 6867 and 4956 msec. per target for the compound (letters), compound and redundant target-task conditions; $\underline{F}$=14.7, (2,18), $p < .01$). The effect of target density was significant over all blocks, as well, ($\underline{F}$=44.5, (2,36), $p < .01$). This effect was due to all three levels of target density being significantly different from each other, (3129, 5008 and 7200 msec. per target for the 2,3 and 4 targets conditions).

Blocks 1-3. The analyses for blocks 1-3 and 4-10 introduced a variety of significant practice effects that were not apparent in the analysis of total time blocks 1-10. First, the analysis for blocks 1-3 maintained the significant three-way interaction for the target-task conditions, target density and blocks. As was seen in the analyses for the compound target-task condition in Chapter 6, this was largely due to the unstable performance in the identification of four, compound targets. The effect was also a function of the redundant target-task condition for four targets. Specifically, for blocks 1 and 3, the four, compound and redundant targets were not significantly different from each other, while they were in block 2. Figure 7-5 shows that this was largely due to the performance as

measured by total time per target for the compound target-task condition becoming longer from block 1 to block 2, and then returning to roughly the same level of performance in block 3 as was seen in block 1. The performance seen in identifying 2 or 3 targets in blocks 1-3, regardless of the target-type, was fairly stable.

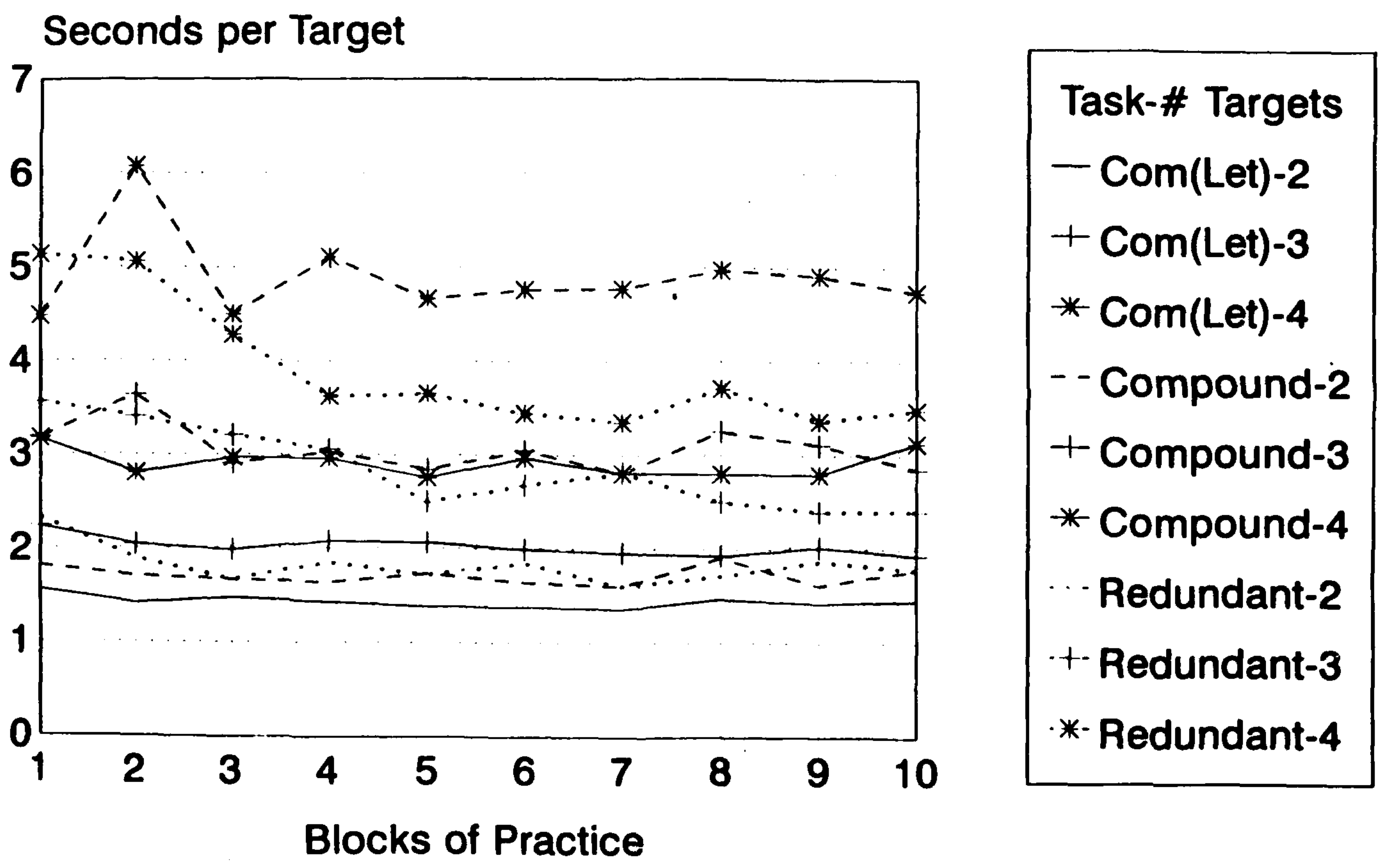
As might be suspected based on the description of the three-way interaction, there was a significant interaction between the target density and blocks manipulations in blocks 1-3, (F=2.0, (4,80), $p < .01$). Again, this interaction was due to the significant slowing in the identification of four compound targets in block 2 of practice relative to blocks 1 and 3 of practice. Further, there was a significant two-way interaction between the target density and blocks in blocks 1-3, (F=2.80. (4,40), $p < .01$). Again, this is attributable to the unusual effects when four, compound targets were being identified because the identification of four targets overall was significantly slower in block two relative to blocks 1 and 3, while the identification of two and three targets was faster through blocks 1-3 of practice. The final two-way interaction was for the target-task conditions by target density, (F=493, (2,40), $p < .01$). As with the analysis over all blocks, all three target-task conditions were significantly different from each other at all three levels of the target density, but the size of the difference was larger as the target density increased, (see Figure 7-7).

All three main effects were significant in the analysis of total time per target data for blocks 1-3. The target-task conditions effect was due to the compound (letters) condition (3745 msec. per target) being significantly faster than the redundant target-task conditions (5799 msec. per target) which was in turn significantly faster than the compound target-task conditions (7937 msec. per target, F=33.5, (2,20), $p < .01$). All three levels of the target density were significantly different from each other (F=493, (2,40), $p < .01$; 3415, 5747 and 8319 msec. per target for the 2, 3 and 4 targets conditions). Finally, block 1 was significantly slower than blocks 2 and 3, which were not significantly different from each other, (5490, 5048 and 4852 msec. per target for blocks 1, 2 and 3).

Blocks 1-4. The analyses for total time per target over blocks 4-10 had a significant two-way interaction for the target-task conditions and target density effects, ($\underline{F}$=40.8, (4,44), $p < .01$). This interaction is consistent with those of the overall analysis, with the compound (letters), compound and redundant target-task conditions being significantly different from each other over all levels of target density, and with the rate of increase in total time per target increasing at different rates as the target density increased, (Figure 7-7). The target-task conditions main effect was significant, with the compound (letters), (3416 msec. per target), being identified significantly faster than the redundant target task condition, (4594 msec. per target), which was faster than the compound target-task conditions, (7451 msec. per target; $\underline{F}$=59.1, (2,22), $p < .01$). All three levels of the target density were significantly different from each other, (3110, 5035 and 7317 msec. per target for the 2, 3 and 4 targets conditions; $\underline{F}$=454, (2,44), $p < .01$). Finally, the analysis of total time per target revealed that block 9 of practice (4959 msec. per target) was significantly faster than blocks 4 and 6 (5275 and 5279 msec. per target).

Input Time. All effects from the analysis of input time per target over all blocks were significant. The three-way interaction found in the percent correct and total time per target data was significant for the input time data as well, ($\underline{F}$=1.57, (36,324), $p < .05$). This interaction, shown in Figure 7-8, is due to essentially the same phenomena seen in the total time per target data, i.e. there was no significant difference over blocks 1-10 for the different target-task conditions when two targets were being identified. With three or four targets, the compound target-task condition was significantly slower than the compound (letters) target-task condition across all blocks. Further, with a target density of three, the redundant target-task condition was not significantly different from the compound target-task condition in blocks 1-7, while in blocks 8-10 the redundant condition was significantly different from the compound target-task condition, but was not significantly different from the compound (letters) target-task conditions. With a target density of 4, the redundant target-task condition was significantly different from the compound (letters) target-task condition in blocks

Figure 7-8. Compound (Letters), Compound, Redundant: Input Time



1, 2 and 3 of practice, and the redundant target-task condition was significantly different from the compound target-task condition in blocks 2 and 4-10. Thus, when three or four targets were being identified the targets in the redundant target-task condition were read from the display and encoded into memory at a rate comparable to the compound target-task condition early in practice, and at a significantly faster rate comparable to the compound (letters) condition later in practice.

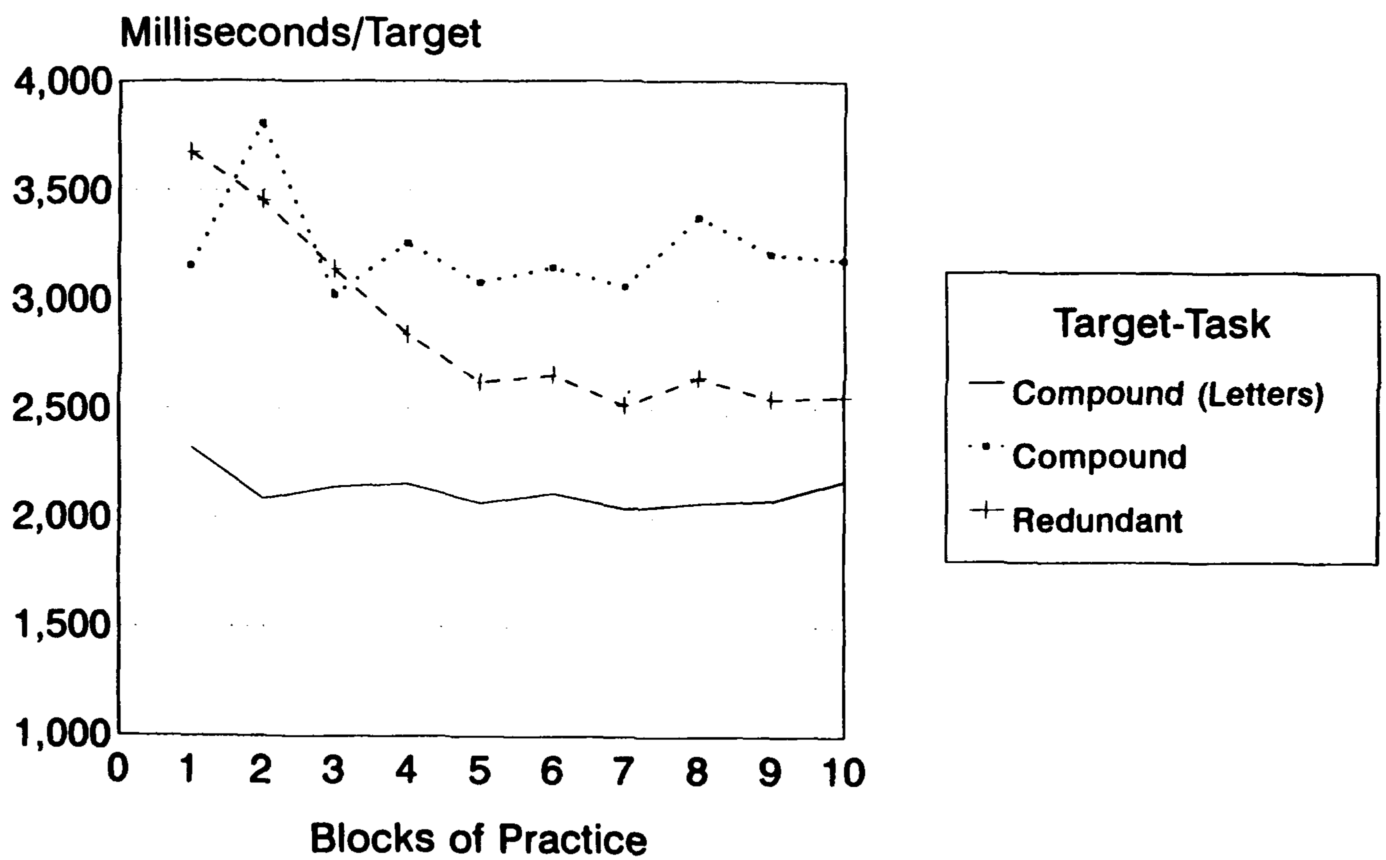
There were three significant two-way interactions in the analysis of input time. The first, which may be seen in the context of Figure 7-8, is for the target density by blocks interactions, ($F = 1.80$, (18,324), $p < .05$). This interaction was due to a significant drop in the mean input time per target over blocks with a density of three or four targets. The target-task by blocks interaction was also significant, ($F = 3.29$, (18,162), $p < .01$; Figure 7-9). This was due to: 1) the compound (letters) target-task condition not changing over blocks while, 2) there was a significant reduction in input time per target for each of blocks 1 through 5 for the redundant target-task condition, and 3) the slower input time per target performance for the compound target-task condition in block 2. The final two-way interaction over blocks 1-10 for the input time per target data was for the target-task by target density interaction, shown in Figure 7-10, ($F = 12.8$, (4,36), $p < .01$). In this interaction, the compound (letters) condition was significantly faster than the redundant and compound target-task conditions, which were not significantly different from each other with a target density of 2 or 3 targets. When 4 targets were identified, the compound (letters) conditions were significantly faster than the redundant target-task conditions, which were in turn faster than the compound target-task conditions. The resulting regressions for each of the target-task conditions may be described by the equations:

$$\text{Input Time}_{\text{Compound (Letters)}} = 741.5\ (\text{Number of Targets}) - 51.0,$$

$$\text{Input Time}_{\text{Compound}} = 1586.0\ (\text{Number of Targets}) - 1445.0, \text{ and}$$

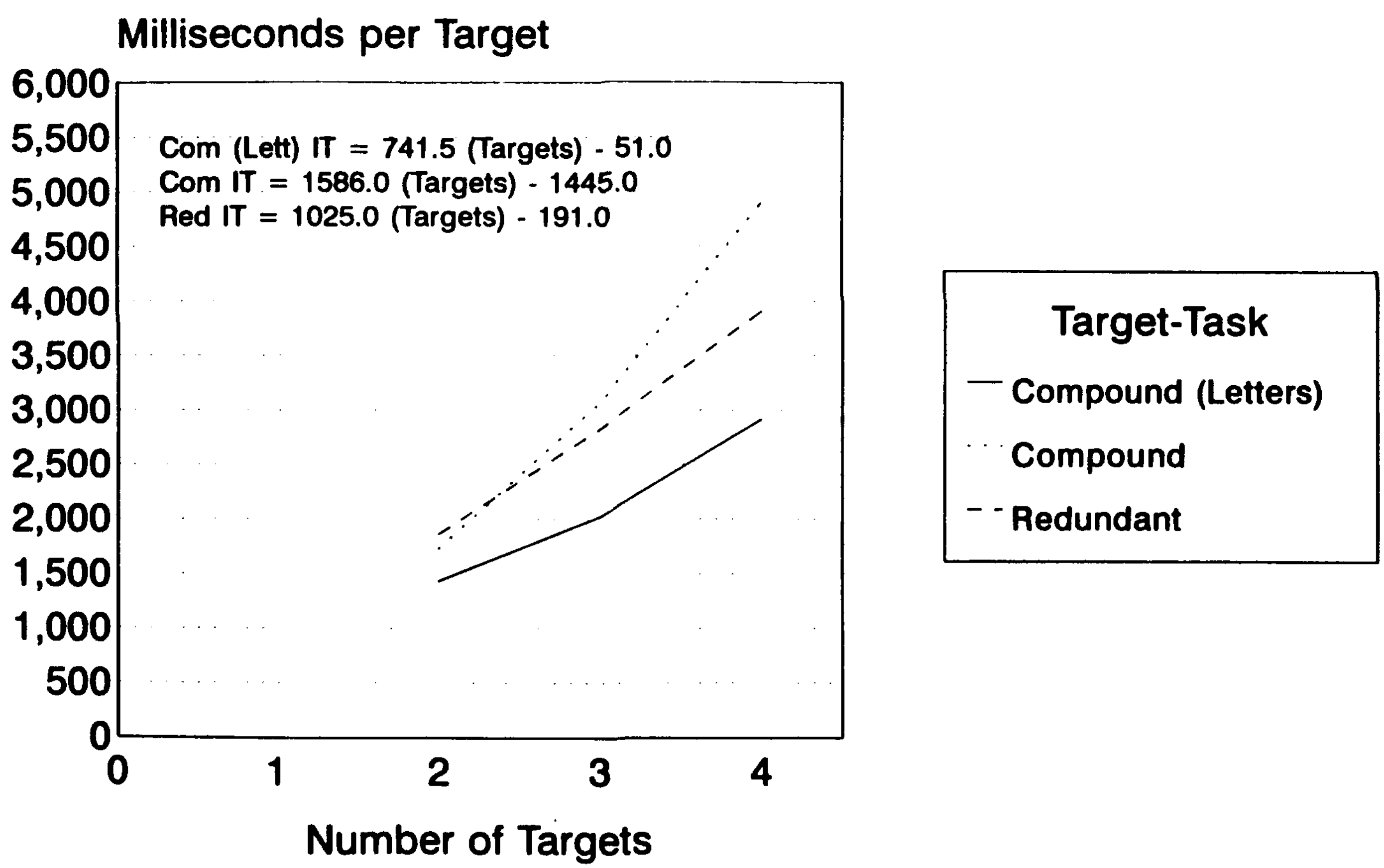
$$\text{Input Time}_{\text{Redundant}} = 1025.0\ (\text{Number of Targets}) - 191.0.$$

Figure 7-9. Compound (Letters), Compound, Redundant: Input Time Target-Task by Blocks of Practice Interaction.



30 July 1992

Figure 7-10. Compound (Letters), Compound, Redundant: Input Time - Target-Task by Number of Targets Interaction.



20 April 1992

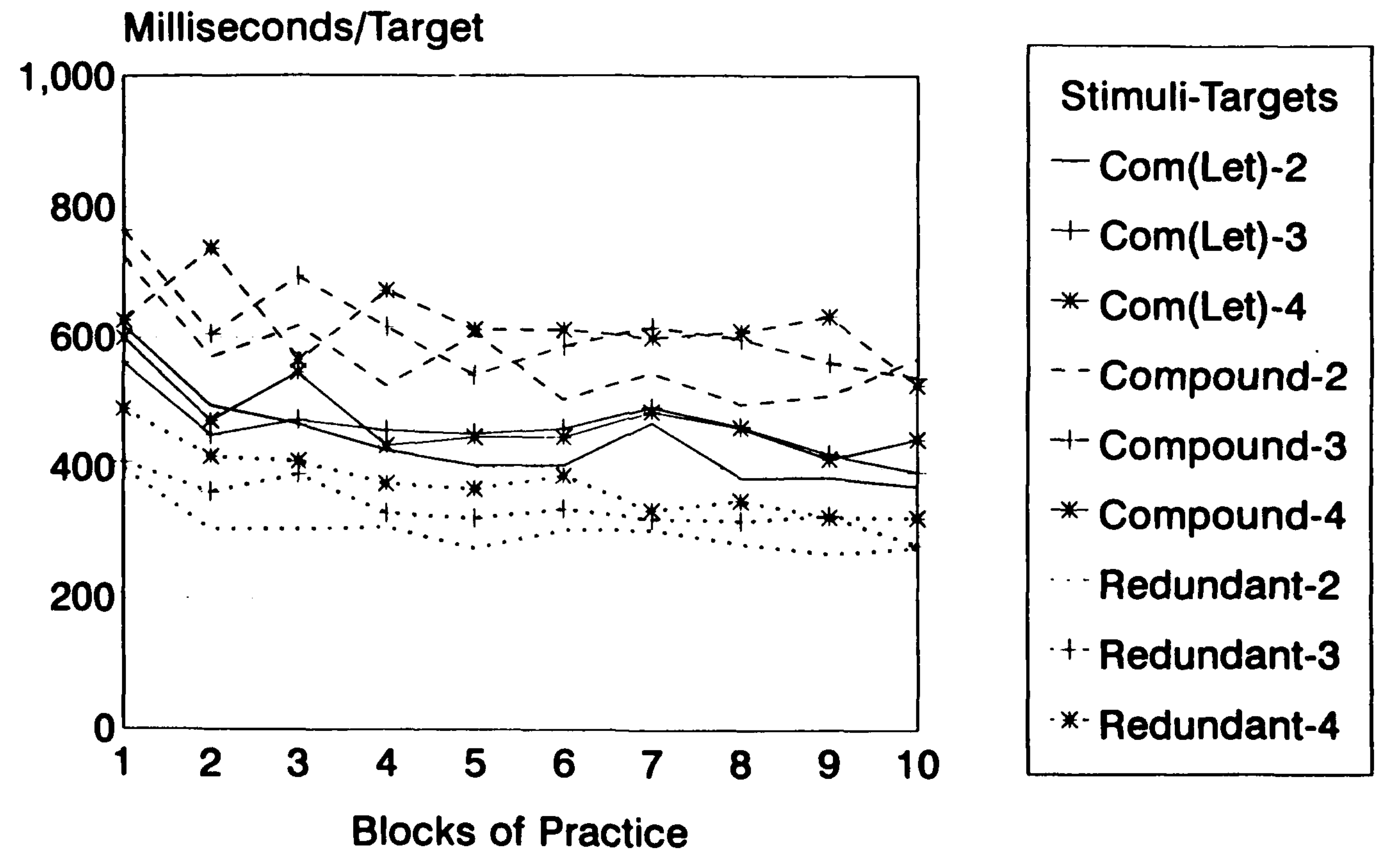
All three main effects for the analysis of input time per target over blocks 1-10 were significant. The target-task conditions comparison was significant at $\underline{F}=29.8$, (2,18), $p < .01$. The compound (letters) condition (2123 msec. per target) was input faster than the redundant target-task condition (2864 msec. per target) which was input faster than the compound target-task condition (3230 msec. per target). All three levels of target density were significantly different from each other, ($\underline{F}=185$, (2,36), $p < .01$; 1672, 2638 and 3908 msec. per target for the 2, 3 and 4 targets conditions). Finally, there was a significant blocks effect, ($\underline{F}=5.07$, (9,162), $p < .01$. The mean performance for those blocks that were significantly different from each other were 3021, 2917, 2695, 2606, 2451 for blocks 1-5. There were no significant differences between block 5 and blocks 6-10).

Blocks 1-3. A significant two-way interaction for target-task condition by blocks, ($\underline{F}=2.94$, (4,40), $p < .05$) was observed. The effect was due to the unusual performance seen in the compound target-task condition wherein compound targets were identified significantly faster than redundant targets in block 1 of practice, significantly slower than redundant targets in block 2, and there was no significant difference between the compound and redundant target-task conditions in block 3. The compound (letters) target-task condition was faster than the compound or redundant target-task conditions over blocks 1-3, and the redundant and compound (letters) conditions showed steady improvement over these three blocks (see Figure 7-9). The second significant interaction for input time was for the target-task conditions by target density. Again, the interaction was essentially the same as that described for this effect over all blocks, (Figure 7-10). There were two significant main effects over blocks 1-3. The target-task comparison was significant, ($\underline{F}=33.5$, (2,20), $p < .01$); 2182, 3794 and 3423 msec. per target for the compound (letters), compound and redundant target-task conditions); and the target density main effect was significant, ($\underline{F}=493$, (2, 40), $p < .01$; 1761, 3039 and 4599 for the 2, 3 and 4 targets conditions). All levels of these factors were significantly different from each other.

Blocks 4-10. The analysis for the input time per target data over blocks 4-10 generated three significant effects. The first was for the target-task by target density interaction, ($\underline{F}$=25.4, (4,44), $p < .01$). This effect, as with the other analyses of input time, was due to the compound and redundant target-task conditions not being significantly different from each other when two or three targets were being identified, though both were significantly different from the compound (letters) conditions, while all three target-task conditions were significantly different from each other with a target density of four targets. As shown by Figure 7-10, the compound (letters) target-task condition was faster than the redundant or compound target-task conditions. When target density was equal to four, the redundant target-task conditions were identified significantly faster than the compound target-task conditions. The main effect for the target-task comparison showed that, the compound (letters) conditions, (2098 msec. per target), were identified significantly faster than the redundant conditions, (2624 msec. per target), which were in turn faster than the compound conditions, (3667 msec. per target; $\underline{F}$=23.8, (2,22), $p < .01$). Finally, as target density increased the rate of identification decreased, ($\underline{F}$=270, (2,44), $p < .01$; 1674, 2683 and 4032 msec. per target for the 2, 3 and 4 targets conditions).

Output Time. As with the other dependent measures for the compound (letters), compound and redundant target-task conditions, the output time data for blocks 1-10 showed a significant three-way interaction for the target-task by target density by blocks effect, ($\underline{F}$=1.48, (36, 324), $p < .05$). The effect was due to the identification of four, compound targets in block 2 of practice, which was significantly slower than the identification of any other target-task conditions in the second block and all conditions in blocks 1, and 3-10 (Figure 7-11). The output time data from blocks 1-10 also showed significant main effects for the target-task comparison, target density and blocks. The target-task effect was due to all three levels of target-task being significantly different from each other over all, ($\underline{F}$=22.9, (2,18), $p < .01$; 460, 600 and 341 msec. per target for the compound (letters), compound and redundant target-task conditions). All three levels of target density were

Figure 7-11. Compound (Letters), Compound, Redundant: Output Time



significantly different from each other as well, ($\underline{F}$=17.0, (2,36), $p < .01$; 438, 472 and 491 msec. per target for the 2, 3 and 4 targets conditions). Output time per target decreased over blocks 1-10 with block 1, (577 msec. per target), being significantly slower than blocks 2-10, (429 msec. per target overall).

Blocks 1-3. For the analysis of output time per target over blocks 1-3, only the target-task conditions, target density, and blocks main effects were significant. All three levels of the target-task conditions were different from each other, ($\underline{F}$=21.7, (2,20), $p < .01$; 520, 685 and 388 msec. per target for the compound (letters), compound and redundant target-task conditions). As the target density increased output time per target increased, ($\underline{F}$=4.55, (2,40), $p < .05$; 503, 534 and 556 msec. per target for the 2, 3 and 4 targets conditions). Once again, block 1 for the output time data proved significantly slower than blocks 2 or 3, ($\underline{F}$=12.2, (2,40), $p < .01$; 579, 503 and 511 msec. per target for blocks 1,2 and 3).

Blocks 4-10. The same significant main effects for the output time data as were significantly different in the same direction for blocks 4-10 as were found for blocks 1-3. The compound (letters) target-task condition, (434 msec. per target), the compound target-task conditions, (624 msec. per target) and the redundant target-task condition, (321 msec. per target) were all significantly different from each other, ($\underline{F}$=36.0, (2,22), $p < .01$). Again, as the target density increased, the output time per target increased, ($\underline{F}$=28.8, (2,44), $p < .01$; 426, 466 and 487 msec. per target for the identification of 2, 3 and 4 targets). Though consistent with the changes in performance seen in blocks 1-3, the significant main effect for the blocks manipulation over blocks 4-10 was unexpected, ($\underline{F}$=2.67, (6,132), $p < .05$). The cause of the effect is uncertain because post-hoc analyses did not reveal any significant differences between the blocks. However, visual inspection of Figure 7-11 show that the output time for block 7, (473 msec. per target) was longer than the output time required for blocks 9 and 10 of practice, (439 and 440 msec. per target, significantly different at p =

.088), so it is speculated that this generated the significant omnibus effect for blocks in this analysis.

DISCUSSION

This study demonstrated that the identification of redundant codes results in performance that is different from the identification of single codes and the identification of multiple codes from single targets. These differences appear in both latency and accuracy. The performance in identifying redundant codes from a target was very similar to the identification of multiple codes from a single target early in practice, and comes to resemble the identification of single codes from complex targets later in practice. Further, the partitioning of response latency into input and output time components demonstrated that the effects of identifying redundant codes are different with regard to the reading of the codes from a display and encoding them into memory, (i.e. input), and the taking of codes from memory and translating them to a response, (i.e. output). As with the discussion found in Chapter 6, the results will not be interpreted in terms of the particular codes or code categorie: used because Chapters 4 & 5 deal extensively with those issues. Rather, this discussion will continue that in Chapter 6 regarding code complexity and extend it to the issue of code redundancy in the context of identifying visual targets.

All the targets in this study were essentially identical in that they consisted of a single letter and single digit code presented adjacent to each other. The difference in the target-task conditions were in the way those codes related to each other and the identification task. In the compound (letters) target-task condition only the letter code in each digit-letter target was relevant to the identification task. In effect, the digit code in this condition was irrelevant noise. In the compound target-task condition, both the digit and letter code were relevant to the identification task, and any element of the letter set could appear with any element of the digit set. With the redundant target-task condition, both the digit and letter codes were relevant to the task (at least in principle)

although, the same letter always appeared with the same digit. Therefore, in the redundant target-task condition, both codes were fully redundant with each other, and knowledge of which letter appeared in the target provided sufficient information to determine the second code. As a result, the second code in each target could be ignored. The question then becomes: How were the redundant codes processed relative to those conditions where 1) two codes were presented, one of which was irrelevant to the identification task, and 2) two, complex, non-redundant codes were presented, both of which were to be identified? This question will be answered by first, looking at the results for each of the dependent measures, then assessing the overall performance for each of the experiment manipulations, and finally describing the results in terms of the predictions.

Dependent Measures

Percent Correct. Accuracy for the compound and redundant target-task conditions were both lower and much more variable than that seen for the compound (letters) condition. Over all the conditions, 94% of the trials were responded to correctly. Therefore, there is little basis to be concerned with a possible ceiling effect. This assertion is further supported by the existence of a number of significant accuracy effects. As for the target-task conditions, the accuracy of target identification was worst for identifying the compound target-task condition, followed by the redundant targets and finally the compound (letters) target-task conditions. Table 7-4 shows that the accuracy in identification in the redundant target-task conditions dropped a net 4.1% relative to the identification of compound (letters) and was a net 12.0% better than the accuracy in identification of the compound target-task conditions overall. Further, the identification accuracy dropped at different rates for each of the three target-task conditions as the target density increased. While there was no significant difference in identification accuracy when two targets were being identified between the target-task conditions, each doubling of the target density caused the accuracy dropped 1.2% for the compound (letters) condition, 8.2% for the redundant target-task conditions and 17.5%

Table 7-4. Compound (Letters), Compound, Redundant: Differences for Significant Main Effects over Blocks 1-10.

Significant Effect	Actual Change	% Change	Actual Change	% Change
	Percent Correct	Percent Correct	Total Time	Total Time
---------------	-------------------	------------	------------------	------------
Comparison:				
Com(Let)-Compound	-14.0	-16.7%	3352	95.4%
Com(Let)-Redundant	-3.8	-4.1%	1441	41.0%
Compound-Redundant	10.1	12.0%	-1911	-38.6%
Targets: 2-4	-15.1	-18.1%	4071	230.1%
Blocks: 1-10	--	--	--	--
*******************	************	************	*************	************
	Input Time	Input Time	Output Time	Output Time
--------------	------------	-----------	------------	-------------
Contrast:				
Com(Let)-Compound	1107	52.1%	140	30.4%
Com(Let)-Redundant	741	34.9%	-119	-34.9%
Compound-Redundant	-366	-12.8%	-259	-76.0%
Targets: 2-4	2236	233.7%	53	12.1%
Blocks: 1-10	-543	-21.9%	-163	-39.4%

Actual Time in MSec./Target. Group means used to generate this Table may be found in Appendix B.
% Change = Actual Change / (Larger of the Mean Times for that comparison) * 100.
30 July 1992. An empty cell indicates the effect was not significant at $p < .05$.

for the compound target-task conditions. These results clearly have implications for interpreting the processing demands in identifying the three different kinds of targets. It can be asserted that the identification of two independent codes in a target entails twice as much processing, or at least twice as much opportunity for error, as does the identification of two fully redundant codes, and 14.5 times the opportunity for error as the identification of one code from a complex (compound) target as from a single code from the same target as measured by performance accuracy.

The effects for processing are clearly moderated by the amount of experience the subject has in performing the task. As suggested by Figure 7-3, this is particularly the case for the redundant target-task conditions. With the redundant target-task conditions, performance early in practice, as measured by the percent of correctly identified trials, resembles the performance seen in the identification of multiple code targets. However, very quickly (over the course of 30 trials) the performance comes to resemble that seen in identifying a single code from complex targets. Thus, although subjects are aware of the relationship between the codes in the redundant target-task conditions at the start of the trials, only after some experience with the task do they perform in such a way as to reflect the redundant nature of the code symbols. The significant three-way interaction between the target-task conditions, the target density and blocks shows that the practice effects for the compound, and particularly the redundant target-task conditions were more pronounced when more targets were being identified. The effects due to practice were further demonstrated in comparing the analyses of blocks 1-3 and 4-10, in which all significant practice effects for the percent correct data were eliminated.

Total Time per Target. When one compares the latency performance for the target-task conditions as measured by total time per target, it is clear that same pattern of performance that was present in the accuracy data was also present in the latency data, i.e. performance in the compound target-task conditions were slower than performance in the redundant target-task condition in which

performance was slower than the compound (letters) conditions. Table 7-4 reveals that performance in the redundant target-task conditions was 41% slower than performance in the compound (letters) conditions, and 38.6% faster than the compound target-task conditions over all blocks. Also, the time required across all the target-task conditions increased as a function of the target density by a factor of 230%.

The target density and the target-task conditions effects in fact were involved in two significant interactions, suggesting that there were different processing demands for the identification of each of the three target-task conditions. The rate of increase for the compound target-task condition (2930.5 msec. per target^2) was 2.3 times that for the compound (letters) conditions (1248 msec. per target^2), and the redundant target-task condition (1929.0 msec per target^2) increased at a rate that was 1.5 times that of the compound (letters) conditions as the number of targets increased. Therefore, it appears that the processing demands for identifying these three conditions were significantly different from each other as measured by total time per target, and the redundant target-task condition had processing demand between those of identifying single codes from compound code targets, and identifying multiple independent codes from compound code targets. The second number of targets interaction was the three-way interaction between the target-task conditions, target density and blocks, which brings us to the issue of how performance changes over blocks 1-10 as measured by total time per target.

Overall, there was no significant change in latency performance over blocks 1-10 of practice. However, the two-way interaction between the target-task conditions and blocks does support the proposition that blocks affected the way the target-task conditions were processed. Further, the analysis of blocks 1-3 of practice reveled that all three target-task conditions improved to one degree or another over the first thirty trials of practice. Figure 7-6 shows these effects, and more to the point, illustrates the far greater improvement in the redundant target-task conditions over blocks 1-

10 than was seen for the compound and compound (letters) target-task conditions as measured by the total time per target data. In effect, the redundant target-task condition was more like the compound target-task condition early in practice, and was more like the compound (letters) condition later in practice. Further, this effect was more pronounced as more targets were being identified, thus generating the significant three-way interaction between the target-task conditions, target density and blocks. Finally, it should be noted that the analysis of total time data later in practice, i.e. blocks 4-10, succeeded in removing the significant practice effect while maintaining the other effects, supporting the proposition that the performance (and processing) early in practice is different from that late in practice. The lone practice effect that remained in the analysis for blocks 4-10 was the presence of a significant main effect for blocks. This effect arose because the performance in block 9 was slightly faster than that seen in blocks 4 and 6, suggesting that some minimal learning continued over all the target-task conditions throughout the course of the experiment.

The consistency of the accuracy and total time per target in showing changes in processing is striking. With each additional block of practice, the total time per target decreased, and the accuracy for each block increased. Teichner (1977, 1979) and Teichner & Williams (1977) propose that processing in an task such as that used in this study be conceptualized as a series of stimulus translations. They argue that during input, there are a series of stimulus-stimulus translations where the information in sensory memory is converted to an appropriate representation in working memory. A series of translations are then performed until the processing task is completed and the responding can begin. Further, the primary effect of practice is suggested to be the reduction in the number of translations required between input and output. The findings in this study of a reduction in time required per target and increased accuracy with practice are entirely consistent with this model. If processing is characterized in terms of translations, the reductions in the number of translations (perhaps because input codes are mapped more and more directly to output codes), the

amount of time required for each target would drop. Further, the development of more direct code translations would reduce the opportunity for errors, because fewer translations would mean that there are fewer translation errors.

Further supporting the Teichner translation model of processing are the empirical results for the redundant target-task condition. It would be intuitively expected that the greatest opportunity for improvement with regard to the target-task conditions used in this study lie in the redundant condition because the two fully redundant codes could be mapped to each other, and/or a single response with practice. Again, the improvement in both accuracy and rate of identification for the redundant condition relative to the non-redundant conditions in this study supports this interpretation. The fact that the rate of identification doubles with practice for the redundant condition is exactly what would be expected if the mechanism generating the change in performance is the improvement in the translation efficiency for two fully redundant codes. In effect, the relationship between the two fully redundant codes means their relationship is less complex than that for the two codes in a compound target, and therefore they can be processed more efficiently. This change in processing efficiency come with practice, through a reduction in the number of code translations. Teichner suggests that the bulk of the translation takes place during input, and therefore the reduction in translations, i.e. processing, that take place with blocks of practice should therefore be found in input with the WiTS model. The changes in input and output will now be considered.

Input Time per Target. All effects from the analysis of the input time per target data over blocks 1-10 proved significant. As with the percent correct and total time per target data, the compound target-task condition was slower overall than the redundant target-task condition, which was in turn slower than the compound (letters) target-task condition. At a mean input time per target of 3230 msec. per target, the compound target-task condition reflected an increase of 52.1% over the

compound (letters) conditions (2123 msec. per target), and an increase of 12.8% over the input time per target required for the redundant target-task condition (2864 msec. per target). These means show that the redundant targets were input 34.9% slower than the compound (letters) targets. Table 7-4 also describes the significant drop in the rate of input as a function of the number of target being identified. Overall, the rate of input dropped 233.7% as the number of targets doubled. Further, both the target-task and target density effects interacted significantly, (Figure 7-10), demonstrating that, as with the total time per target analyses, the processing required for each of the three target-task conditions increased differentially as the number of targets increased. The identification of redundant targets increased at a rate of 1025 msec. per $target^2$, or 1.4 times the increase seen for the identification of a single code from a multiple code target, (741.5 msec per $target^2$ for the compound (letters) condition). The identification of multiple, non-redundant codes from a single target increased at a rate of 1586 msec. per $target^2$, or 2.1 times the rate of increase for the identification of single targets and 1.5 times the rate of increase for redundant targets over all. Thus, it can be concluded that the processing involved with reading redundant codes from a display and encoding them into memory (input) is less complex than the encoding of multiple, unrelated codes from targets, and is more difficult than the encoding of single codes from multiple code targets, as was argued above. The rate of increase in the time required to read targets from a display and encode them into memory as a function of target density, and was moderated by significant blocks effects, specifically in the form of a three-way interaction between the target-task conditions, target density and blocks of practice.

There was a significant main effect for practice over blocks 1-10 for input time per target, where performance improved significantly overall for each of blocks 1-5. Further, the amount of improvement was affected by 1) the particular type of target-task being performed and 2) target density. In effect, the greater the target density, the greater the benefit from practice. Also, the largest and most consistent improvement was seen in the redundant target-task conditions, and the

greater the number of redundant targets being identified, the greater the improvement. Thus, the presence of the significant three-way interaction and the significant two-way interaction between number of targets to be identified and blocks, (both illustrated by Figure 7-8), the target-task by blocks interaction effect, (illustrated by Figure 7-9), and the significant overall main effect for blocks. These results are total consistent with Teichner's description of input processing as a series of stimulus-stimulus translations (T_{S-S}), and the reduction of the number of translations required with practice on the task. Further, the similarity of input latency for the compound and redundant conditions early in practice, and the redundant and compound (letters) conditions late in practice suggest that the redundant codes come to be processed as a single code in input with a sufficient amount of practice.

The partitioning of the input time per target data into early and late practice served the purpose of eliminating the significant blocks effects, confirming that the majority of learning had been completed within 30 trials of practice, though there was still a significant target-task by blocks interaction over blocks 1-3. This effect was due to the rather unusual performance seen in the compound target-task condition as measured by the percent correct, total time per target and input time per target data. In effect, these measures indicate the performance with the compound target-task condition got more accurate but slower as subjects went from block 1 to block 2 of practice. As subjects went to block three of practice, however, performance stayed as accurate, but the input and total time per target got significantly faster. Apparently, the complexity in performing the compound target-task identification, particularly when larger numbers of targets were being identified, caused subjects to adjust their performance criteria such that they improved accuracy at the expense of latency in block 2 of practice, and then improved the latencies of their performance while maintaining accuracy in block 3 of practice. With regard to the target-task conditions and target density, and their interaction, the direction and size of these effects were consistent with those described for the overall analysis across blocks 1-10 for the input time per target data.

Output Time per Target. The performance seen in the target-task conditions as measured by output time was clearly different from that seen in the percent correct, total time and input time per target measures. This is particularly clear in the significant main effect for the target-task conditions, in which the redundant target-task condition was responded to significantly more quickly than the compound (letters) or compound target-task conditions. As may be seen from Table 7-4, the overall output time per target for the redundant target-task condition was 34.9% faster than the compound (letters) target-task condition, and 76% faster than the compound target-task condition. This shows that at least one aspect of output processing, i.e. either the taking information from memory, translating it to a response and/or executing the response was less demanding than that for the compound and compound (letters) target-task conditions. The finding of a significant main effect for target density, which showed a 12.1% increase in the output time required per target as the number of targets increased from 2 to 4, suggests that some of this output effect for the identification of redundant targets must be attributable to processing associated with the redundant as compared to compound and compound (letters) target-task condition, rather than simply the mechanics of executing the responses. This assertion is further supported by the significant three-way interaction between the target-task conditions, target density and blocks. Examination of Figure 7-11 reveals that not only was the output time associated with the redundant target-task condition faster than that for the other target-task conditions, but also improved less over blocks, and was less variable overall. Because target density is assumed to be a factor that affects the information processing aspects of the identification task, and it appears that the redundant target-task condition appears to be less affected by the target density in the output time per target measure, it can be argued that there must be less information being processed in the output of redundant targets. Again, such a finding is consistent with the conceptual treatment of processing as a series of stimulus translations. Therefore, it is suggested that the individual codes in the redundant targets are in fact treated in processing as a single code in output. The relative speed of output seen

for the redundant target-task condition reflects the additional movement time required to execute two responses to the same code, i.e. plan and execute the same response twice.

The analyses for blocks 1-3 and 4-10 had the effect of eliminating the significant three-way interaction between the target-task conditions, target density and blocks. However, the target-task, target density and blocks main effects remained significant in the analysis of both blocks 1-3 and 4-10. Therefore, it can be concluded that the essential effects seen in output time were persistent across both early and late practice, as may be surmised from Figure 7-11.

Experiment Manipulations

Target-task Manipulation. The results above make it clear that the compound (letters), compound and redundant target-task conditions affected the performance of the identification task. The identification in the compound (letters) condition, with the identification of single codes from compound targets, was both more accurate and, with regard to total time per target and input time per target, faster than the identification of two fully redundant codes from compound targets, or two non-redundant codes from compound targets. Further, both the overall rate of responding and the rate of input of the redundant targets was faster than that for identifying non-redundant codes within a target, particularly as more targets were presented on the display to be identified, and/or after 30 or so trials of practice. What is particularly interesting in this study, is that the reading of redundant codes from a display and encoding them into memory should be slower than the input of the single (letter) codes, while the output of the redundant codes is significantly faster than the output for the single (letter) codes. What makes this even more noteworthy is that the redundant target-task conditions requires twice as many responses as the compound (letters) target-task condition, and findings in chapters 4-6 that suggests that the more responses that are required, the slower should be the rate of output. This supports the assertion that there is something different about the way the

codes in the redundant targets are processed relative to both the compound (letters) codes and the compound codes.

The fact that the input time per target for the redundant target-task conditions is longer than that for the compound (letters) condition, suggests that both codes in the redundant target-task condition are being read into memory and processed. However, because the redundant codes are input faster than the same number of non-redundant codes in the compound target-task conditions indicates that while both codes are being processed in the redundant target-task condition, they are not being processed in the same way as comparable non-redundant codes on a qualitative basis. Once the redundant codes are encoded from sensory memory however, the second of each of the fully redundant codes apparently receives minimal processing, and this enables the output of the two, fully-redundant codes to be much faster per code than that for targets in which single codes are relevant, or targets which have multiple codes that must be attended to, but in which the codes are not related (redundant)[21]. These results may indicate that only one of the redundant codes in memory is in fact processed during output.

Target density. The more targets there were to identify the worse the performance as measured by both accuracy and latency. Further, there was a significant interaction between the target density and the target-task effects as measured by accuracy, total time per target and input time per target. Thus, as more targets were to be identified, the less accurately and more slowly were the targets

---

[21]An interesting caveat with regard to the particular conditions used in this study is appropriate at this time. This study created redundant conditions where the two redundant codes required exactly the same response, i.e. the response mappings for each of the redundant codes was also fully redundant such that both redundant codes could be responded to correctly by simply executing every response twice. An interesting variation of this study would be to utilize an alternative response mapping so that a different response was required for the execution of each of the fully redundant codes. This could be done simply by utilizing the separate response panel mapping described in chapter 3, or by changing the redundant pairs, e.g. A3, B2, etc. rather than the mapping A1, B2, etc. used in this study. With this manipulation it should be possible to assess the relative change in output time per target in terms of response redundancy as opposed to display code redundancy.

identified, and the effect was greater for the compound target-task condition than it was for the redundant target-task condition, which was in turn more affected than the compound (letters) target-task condition. With the exception of the significant three-way interaction between target-task, number of targets and blocks, (which is explained by the redundant target-task condition benefitting more from practice relative to the other target-task conditions), the locus of the number of targets and target-task interaction can be said to be in input processing. That this effect should be associated with the reading of codes from the display and being encoded into memory is consistent with the WiTS processing model (Teichner, 1977, 1978; Teichner & Williams, 1977). Therefore, it can be concluded that the bulk of the latency and accuracy decrements found in these identification tasks is located in input processing.

Blocks of Practice. The most impressive aspect of the blocks effects in this study is the differential effects practice had on the different target-task conditions. As is most clearly shown by the significant interactions for the target-task conditions by blocks for accuracy (Figure 7-3), total time per target (Figure 7-6) and input time per target (Figure 7-9), the redundant target-task condition got more accurate and faster with practice relative to the improvements with practice seen for the compound (letters) and compound target-task conditions. Again, that the output time per target measure should not contribute to this interaction suggests that the bulk of the learning is associated with the processing involved with reading information from a display and encoding it into memory. This is not to say that there were no performance improvements due to blocks indicated by output time. In fact there were significant main effects for the blocks and output time per target as measured across all blocks, blocks 1-3 and blocks 4-10. However, because these were simple effects and not implicated to a significant degree with processing by virtue of a significant interaction with the target density, it is suggested that the learning associated with output is essentially learning to execute responses rather with the output processing per se.

Results Summary

The results for each of the experimental predictions is summarized below:

1. The input latencies associated with the redundant target-task conditions were not significantly different from those of the compound target-task conditions early in practice, but were significantly different later in practice. Further, the redundant input latencies were significantly different from the compound (letters) target-task condition early in practice but were not different later in practice. Therefore, it is concluded that early in practice both of the redundant codes are being processed as if they were not redundant, but as they are recognized as being redundant, the two redundant codes come to be treated as single codes, in accordance with prediction 1. It is not clear that the processing of redundant codes late in practice is in fact identical to that of the single codes identified in the compound (letters) condition, however. This caveat arises due to the significant overall difference between the redundant and compound (letter) target-task conditions in the analysis from blocks 4-10 of practice. It may be that if performance with additional blocks of practice were measured, that any difference between the redundant and compound (letters) target-task conditions would ultimately disappear. However, that cannot be stated definitively based on the data from this study.

2. Prediction 2 states that if the rate of processing for the redundant target-task condition is approximately half that seen for the compound and compound (letters) conditions, then only one of the redundant codes in each target is being processed during output. Table 7-4 describes the percent of change in the target-task contrast as a drop of 34.9% when comparing the redundant target-task to the compound (letters) condition, and a drop of 76% when comparing the redundant target-task condition to the compound condition.

Therefore, it appears that prediction 2 should be accepted, and that on average at least, the amount of processing seen with the redundant target-task conditions is approximately half that seen for the conditions where all the codes identified must be independently processed.

Objectives

The general objectives of this study were essentially the same as for the other studies described in this report. They were to:

1. Apply the Within-Task Subtractive methodology for response time partitioning to the study of redundant information codes and discuss the results in the context of a) performance in a target identification task, and b) assessing the theoretical and practical implications of the results found; and

2. Assess the relative performance of identifying codes in targets in which the codes are redundant, the codes are both different and relevant, or the codes are different and one of them is irrelevant.

Both objectives 1 and 2 have been met in this study. The partitioning of the total time per target measure into input time and output time components has demonstrated that redundancy in codes has a differential effect on how codes are read from a display and encoded into memory versus the taking of information stored in memory, translating it to responses and executing the appropriate responses. The results obtained were often either not present in the total time measure, or were in fact totally different for input and output time. For example, the total time per target measure revealed that the identification of redundant targets was both faster and more accurate than the identification of multiple code, non-redundant targets, and both slower and less accurate than the

identification single codes from multiple code targets. This finding was essentially confirmed in the input time measure, indicating that both codes in the redundant targets were affecting input processing, i.e. were being read. However, the redundant codes were read more rapidly than non-redundant codes, particularly as more and more codes were identified during a given task. The output time per target measures showed that the redundant target-task conditions were responded to more quickly than either the single codes (compound-letters) or multiple code, non-redundant (compound) targets. This difference in the relative performance between input and output time was taken to show that though twice as many responses were required from the redundant target-task conditions as the compound (letters) conditions, only a single code was being processed during output in the redundant code conditions. These findings therefore confirm the merit of the WiTS methodology, and the utility of measures relating to input and output processing in understanding human performance with different processing tasks and different information codes.

The relationship of total, input and output time, as well as the processing for each of the coding conditions used in this study is directly illustrated in Figures 7-12 and 7-13. Figure 7-12 shows the relative performance of the total, input and output time per target measures as a function of the target density and the different target-task conditions over all blocks of practice. Figure 7-13 was derived from Figure 7-12. The only difference is that the latency measures are calculated on the basis of the number of codes identified, rather than on the number of targets identified. Figure 7-14 reflects this same data for blocks 4-10. Because the compound (letters) have only one code that is relevant to the identification task, the regressions on the basis of number of targets and number of codes are in fact identical. The regressions for the three target-task conditions on a per target basis, (Figure 7-12) are:

$$\text{Total Time}_{\text{Compound (Letters)}} = 1248.0\ (\text{Number of Targets}) - 178,$$

$$\text{Input Time}_{\text{Compound (Letters)}} = 741.5\ (\text{Number of Targets}) - 51,$$

$$\text{Output Time}_{\text{Compound (Letters)}} = 16.0\ (\text{Number of Targets}) + 411,$$

Figure 7-12. Compound (Letters), Compound, Redundant: Total, Input & Output Time by Number of Targets.

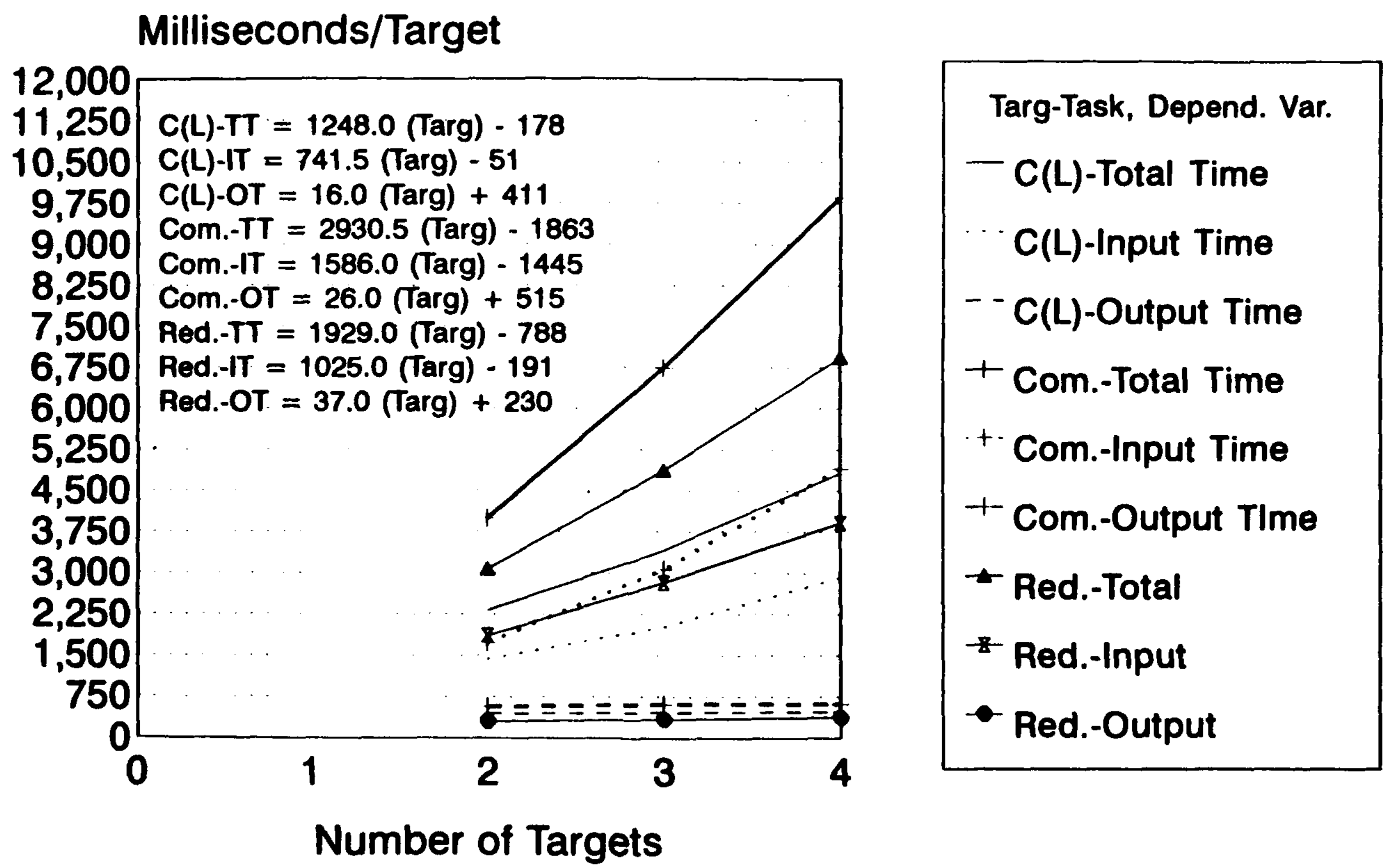
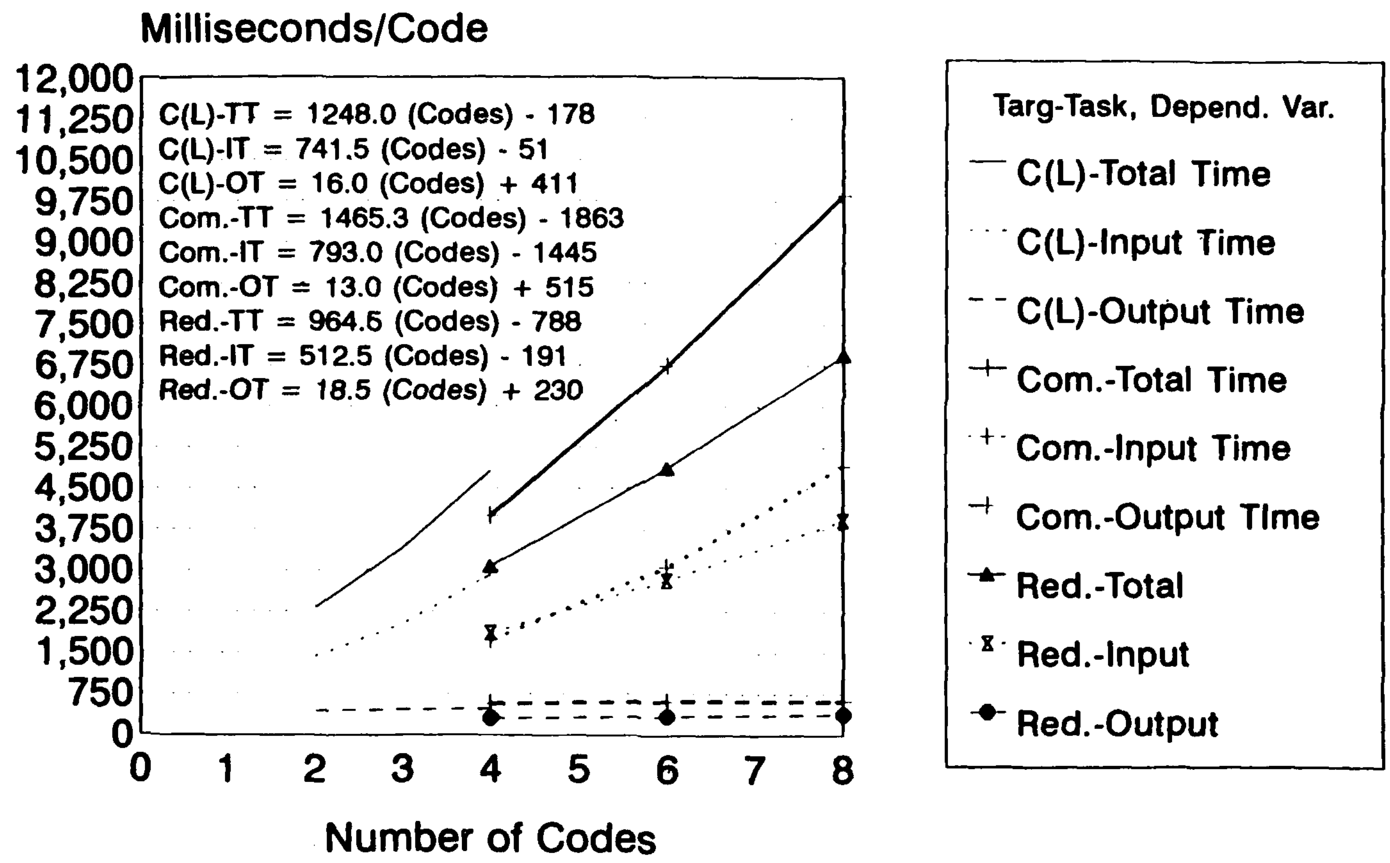
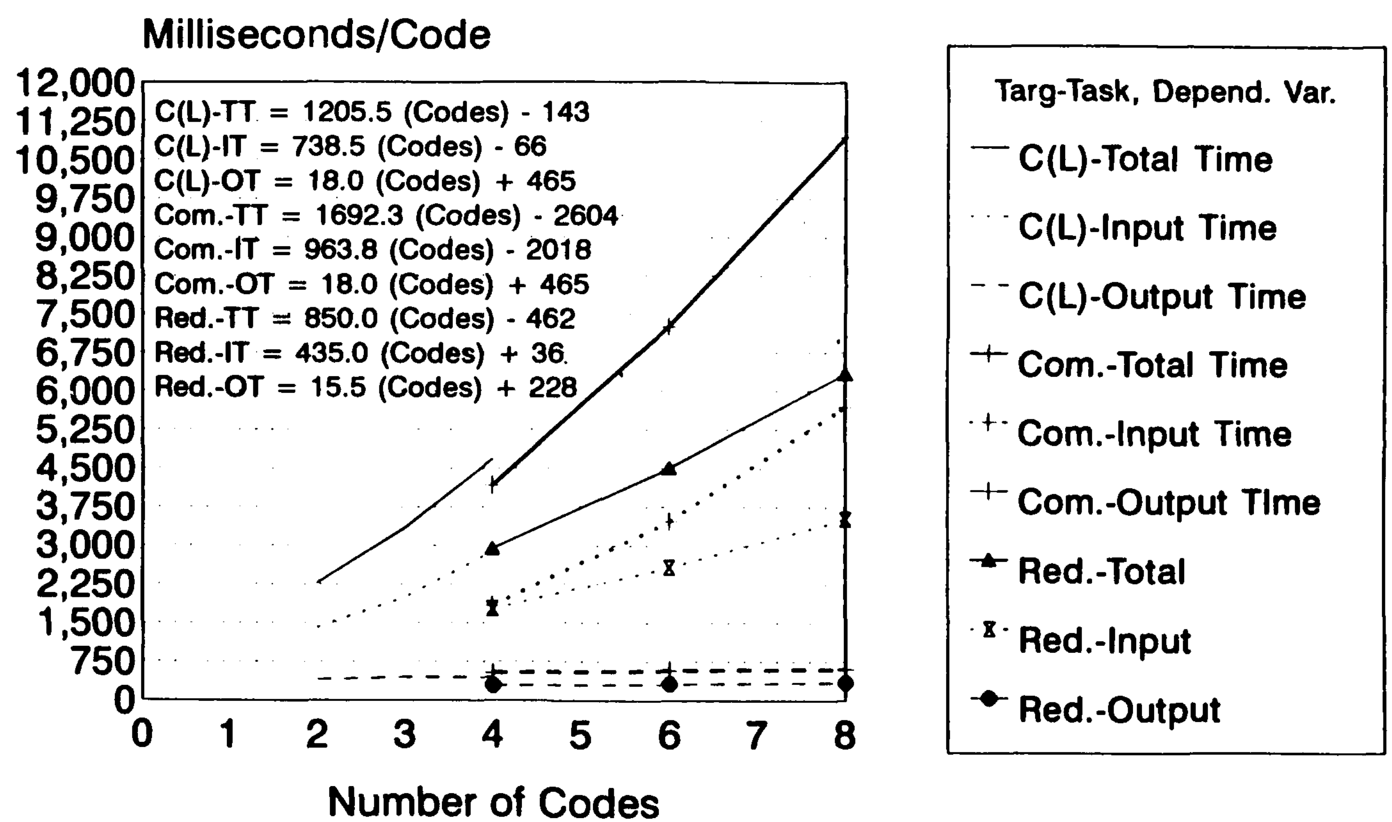


Figure 7-13. Compound (Letters), Compound, Redundant: Total, Input & Output Time by Number of Codes Identified.



22 April 1992

Figure 7-14. Compound (Letters), Compound, Redundant: Total, Input & Output Time by Number of Codes Identified. Blocks 4-10.



$$\text{Total Time}_{\text{Compound}} = 2930.5\ (\text{Number of Targets}) - 1863,$$

$$\text{Input Time}_{\text{Compound}} = 1586.0\ (\text{Number of Targets}) - 1445,$$

$$\text{Output Time}_{\text{Compound}} = 26.0\ (\text{Number of Targets}) + 515,$$

$$\text{Total Time}_{\text{Redundant}} = 1929.0\ (\text{Number of Targets}) - 788,$$

$$\text{Input Time}_{\text{Redundant}} = 1025.0\ (\text{Number of Targets}) - 191,$$

$$\text{Output Time}_{\text{Redundant}} = 37.0\ (\text{Number of Targets}) + 230.$$

The regressions on a per code basis, (Figure 7-13), are:

$$\text{Total Time}_{\text{Compound (Letters)}} = 1248.0\ (\text{Number of Codes}) - 178,$$

$$\text{Input Time}_{\text{Compound (Letters)}} = 741.5\ (\text{Number of Codes}) - 51,$$

$$\text{Output Time}_{\text{Compound (Letters)}} = 16.0\ (\text{Number of Codes}) + 411,$$

$$\text{Total Time}_{\text{Compound}} = 1465.3\ (\text{Number of Codes}) - 1863,$$

$$\text{Input Time}_{\text{Compound}} = 793.0\ (\text{Number of Codes}) - 1445,$$

$$\text{Output Time}_{\text{Compound}} = 13.0\ (\text{Number of Codes}) + 515,$$

$$\text{Total Time}_{\text{Redundant}} = 964.5\ (\text{Number of Codes}) - 788,$$

$$\text{Input Time}_{\text{Redundant}} = 512.5\ (\text{Number of Codes}) - 191,$$

$$\text{Output Time}_{\text{Redundant}} = 18.5\ (\text{Number of Codes}) + 230.$$

Of interest with regard to processing is the slopes of each of the regressions shown in these figures. The slopes indicate the rate of increase in each of the latency measures as a function of the target density. With regard to input, and on a per target basis, (Figure 7-12), the redundant targets (1025.0 msec. per target^2) require more time per target to be identified than do the compound (letters) targets (741.5 msec. per target^2) and require less time per target to be identified than the compound targets (1586.0 msec. per target^2). However, on a per code basis, the input time per code for the compound (letters) targets and compound targets are virtually identical, (741.5 and 793.0 msec. per code^2) and the relevant codes in these targets require more time per code than do the

codes in the redundant condition (512.5 msec. per code^2). The comparison of the target-task conditions on a per target and per code basis carries over to the assessment of output time per target as well. That the time required to process relevant but fully redundant codes should be less than that required for relevant but non-redundant codes is appealing on an intuitive basis. The codes in the redundant condition have less information associated with them because knowledge of one of the codes gives complete knowledge of the second code. Therefore, less time needs to be spent in reading the two codes on a per code basis, than with non-redundant codes.

The change in output time per target required for each additional target for the compound and redundant target-task conditions (26.0 and 37.0 msec. per target^2 respectively) is also about twice that required for the compound (letters) conditions (16.0 msec. per target^2). Again, on a per code basis, the slopes of the regressions are virtually identical (16.0, 13.0 and 18.5 msec. per target^2 for the compound (letters), compound and redundant target-task conditions). This supports the notion that the output processing for the relevant codes in each of the three tasks is comparable and occurs at the same rate, and that the differences seen in output time on a per target basis are in fact due to differences in the number of relevant codes being processed in output by virtue of the task requirements for each of the target-task conditions. Further, the intercept difference seen in output for the redundant task condition probably corresponds to the fact that the second response for each redundant target requires the pressing of the same button twice (Fitts, 1954).

Applications & Lessons Learned

As with the study reported in Chapter 6, the applications of this study will be illustrated through the presentation of the results in terms of principles and guidelines.

1. Redundant codes are read from the display and encoded into memory faster than non-redundant codes on a per code basis, i.e. the time required to input each of the fully

redundant codes is faster than the time required to input a comparable non-redundant code on a per code basis. However, because the second redundant code by definition carries no information, the net performance in identifying redundant targets is slower than that for identifying single codes, at least early in practice.

2. Once fully redundant codes are encoded in memory, there is no processing cost associated with the redundant codes on the output side of the task. Examination of the slopes and intercepts of Figures 7-12 & 7-13 suggest that the differences in output time per target are due to the physical movement times associated with repeating every response twice in the redundant condition, and this repetition does not involve any additional processing per se. Future studies should examine this finding in more detail through the use of alternative response panel mappings.

3. The more targets there are to be identified, the worse the performance in terms of both speed and accuracy. This finding was true for all three target-task conditions where the rate of responding and accuracy both decreased as the number of targets increased. However, the amount of decrement in performance with increasing numbers of targets was moderated by the particular target-task condition. The performance got worse fastest as the number of targets increased for the identification of compound targets where both the codes in each target were relevant and unrelated. Performance decreased the least as the target density increased when a single code from each target was being identified. The redundant targets, where both codes in each target were relevant but were fully redundant with each other decreased at a rate that was both significantly worse from the identification of single codes and significantly better than the identification of multiple unrelated codes.

4. Performance on all the conditions improved in terms of both speed and accuracy. However, the improvement seen in the redundant target-task condition benefitted far more from practice, and the improvements continued over a larger number of trials than with the non-redundant target-task conditions. The effect of practice was so extensive with the redundant condition that the performance early in practice was comparable to that with identifying multiple codes from single targets (compound) while late in practice (after 70 trials or so) performance with the redundant targets was comparable to that with identifying single codes from targets (compound-letters).

5. The results of this study suggest the use of fully redundant codes should be avoided when a task is going to be performed relatively infrequently and/or by inexperienced users because the additional codes entail additional processing and this will lower the rate of target identification and accuracy of identification. This guideline is particularly relevant when large numbers of targets may be present on the display for identification.

6. The subjects in this study were explicitly informed of the nature of the identification task and the relationships of the codes in the displays for each task. Thus, subjects in the redundant target-task condition were aware that the two codes in each target would be perfectly correlated. That there should still be such dramatic learning effects with the redundant target-task conditions therefore emphasizes the importance of experience with the task in learning to perform it, and that task instructions can not be expected to compensate for the effects different information codes and coding schemes will have on performance.

7. The comparison of the performance seen in this study with the experimental manipulations in terms of the target density and the number of codes being identified shows the value of using both measures in understanding performance. The benefits of this approach were

particularly clear when they were combined with the WiTS methodology, and the assessment of input and output processing derived from that methodology. Future studies should continue to compare the rate of change in performance with changes in the number of targets and/or codes to assess the effects on information processing.

8. The Teichner & Williams (1977) description of processing proved entirely consistent in terms of explaining the results found. Processing may be conceptually thought of as a series of stimulus translations. Most of these translations take place during input, and thus, input requires more time per target than does output. When a task is relatively novel, more translations are required than when the subject has had experience on the task. As a subject becomes experienced with performing a task, the more directly he or she may map codes in the display to responses. The more consistent the relationship among the codes in a task, the faster the reduction in codes will take place with practice. The issue of processing and the development of a general processing model for the type of identification task used in Chapter 4, 5, 6 and 7 shall be the topic of Chapter 8.

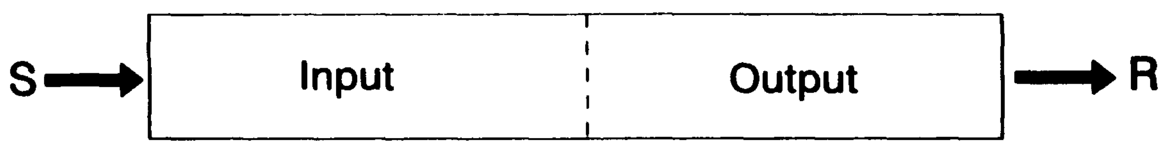
CHAPTER 8 - General Discussion

The studies described in Chapters 4-7 investigated a number of issues relating to the effects of various display and response codes on performance in input and output times. It is now appropriate to revisit the major findings from these studies and consider them in a more general theoretical context. So far in this report, the research findings have been considered only in terms of the general model described by Teichner (1977, 1978) in developing the Within-Task Subtractive (WiTS) methodology. The WiTS model states that a discrete information processing task, (as opposed to a continuous control task), can be thought of as consisting of a sequence of two stages: input and output (Figure 8-1). As discussed in detail in Chapter 3, input consists of all that processing that occurs following the onset of a stimulus in a display, including the acquisition, encoding, and ultimate storage in a non-sensory or working memory. This stage is followed by the output stage that includes all those processes following the storage of information in memory, including response selection and execution. The only requirements for the model were the assumptions that:

1) There be a non-sensory (e.g. working) memory, and
2) The requirement that input stops and output begins when all of the items to be stored in memory, have been stored.

However, Teichner (1977) notes that the second assumption is not rigid. In fact, it may be that processing is not strictly sequential, and may in fact be something of a cascade as long as the stages are approximately sequential.

Figure 8-1. Teichner's WiTS Processing Model.



In order to provide a more detailed context for interpreting the findings from Chapters 4-7, it is appropriate to begin this discussion with an overview of a more detailed processing model that influenced the development of the Within-Task Subtractive (WiTS) methodology. Teichner & Krebs (1974) developed a general processing model based on their survey of the choice reaction time data up to that time. The basic model is:

$$P = f_1(a) + f_2(T_{S-S}) + f_3(T_{S-R}) + f_4(R\text{-}Sel) + f_5(R\text{-}Ex)$$

where: **P** = Performance, measured by time, speed or error, or a combination measure such as the amount of information transmitted;

f_x = empirical determined constants for a particular task and level of practice;

a = that portion of performance associated with stimulus encoding (in the sensory register), and is limited in part by the activation properties of the stimuli. This aspect of processing operates in a manner similar to Grice's Variable Criterion Performance Model (Grice, Nulmeyer & Spiker, 1982; Grice, Canham & Gwynne, 1974; Grice & Gwynne, 1987). Teichner & Williams (1977) describe the **a** term mathematically as:

$$a = a_s + a_k + RT$$

a_k = a constant associated with neural transmission speed,

a_s = a stimulus encoding constant associated with the activation or arousal properties of the stimulus[22].

---

[22]It is well established that various properties of a display and/or stimulus may affect performance, e.g. the brightness of the stimuli, the color of the stimuli, etc., and these have incidental effects on performance. For instance, brighter displays tend to generate faster reaction times than do dimmer stimuli or displays. The color red is often cited as having arousing properties which lead to faster response times, though the color or brightness may not have any intended relevance to the task (e.g Morrison, 1977). The a_S term is intended to account for these properties and their effects on performance.

RT = simple reaction time component of Donders' subtractive model for recognizing that a stimulus has occurred, and which is dependent in part on the particular nature of the information conveyed by the stimulus.[23]

$T_{S\text{-}S}$ = the time required for a Stimulus-Stimulus Translation. Conceptually, there may be a series of such translations before the information in the display is in a form suitable for storage in memory.

$T_{S\text{-}R}$ = the time required for a Stimulus-Response Translation. Teichner & Krebs suggest that there is a single translation process which takes the information stored in memory and, in effect, selects the appropriate responses.

R-Sel = the time required to take the desired responses, as determined by $T_{S\text{-}R}$ and convert it to appropriate response actions, i.e. develop the correct motor program for implementing the desired responses. This response-selection phase of the model may be considered to be relatively constant for a given task and level of performed experience with a particular task's response demands.

R-Ex = the time associated with executing the motor responses and the processing involved with monitoring the response execution. Teichner & Williams note that this can be considered a constant for a given, well learned motor activity.

In essence, the model states that performance in a task is the product of a serial system. The model is based on the definition of a task as involving the transfer of information between components. Each term in the model can be considered for discussion purposes to represent a function or sub-

[23]Teichner & Krebs (1974) showed that the time to recognize the occurrence of a reversed 'F' was longer than a standard 'F', suggesting that in fact simple reaction time varies considerably as a function of stimulus information.

task, and each sub-task involves a transfer of information. The functions called out in the Teichner & Williams model include an arousal mechanism which is associated with the extraction of information from sensory memory. This *a* term therefore operates in a manner similar to the variable criterion theory[24] wherein a decision is made as part of sensory processing that a certain stimulus has occurred, and the decision is affected by certain higher-order factors such as task context and expectation. Stimuli which are detected are then passed along to the first, translation stage where a series of operations are performed on the stimuli to translate them to a form appropriate for completing the task (T_{S-S}). The arousal and first translation effectively constitute input processing in the Teichner (1977, 1978) WiTS model. When the stimulus (or stimuli, depending on the task demands) have been adequately processed, output processing can begin. At this point the results of the input translations will be translated again, however this time the translation involves the selection and execution of the desired responses (T_{S-R}). This information is then passed to a response selection stage, in which a sequence of coordinated motor control movements are generated (R-Sel). This information is used actually to execute the responses. The motor movements are in fact monitored and modified during execution as needed (R-Ex). The results obtained in the studies described in this report are consistent with this processing model. The major results from Chapter 4-7 will now be reviewed, and related to the processing model.

[24]Variable criterion theory, as advocated by Grice and his students, suggests that information is accumulated from the sensory store at a variable rate depending on such factors as stimulus contrast, brightness, etc.. Evidence accumulates in a manner consistent with a random walk model. The information regarding the existence and identify of a stimulus continues to accumulate until it crosses a threshold, at which point it is passed to working memory to be processed as a code. The amount of information required to identify that a stimulus has occurred, i.e. the set point for the criterion, is set in large part by the context of the information task, and factors which affect the expectation that a certain type of stimulus will occur. Thus, the evidence for the occurrence of different stimuli accumulates according to a random walk, and the criterion which is used to judge that a certain stimulus has occurred is variable and set by the observer according to a variety of cognitive factors. For a more complete discussion of random walk models, and the variable criterion theory, see: Grice, Nulmeyer & Spiker, 1977, 1982; Grice, 1968; Swanson & Briggs, 1969; Laming, 1968; Edwards, 1965.

Major Findings.

The major findings from the studies described in Chapters 4-7 will now be described and related to the Teichner & Williams model, with an eye towards the consistencies and discrepancies of the results with each other and the model. From the review of these findings, it is intended that the model can be assessed in terms of its adequacy in describing the empirical findings. Chapters 1 and 2 suggest the following general conclusions:

1. Different codes of categories, even when those codes are very similar, can lead to different performance as measured by the overall rates of processing, input processing, and output processing.

2. The processing of codes from multiple code categories causes the rate of input processing to be done at a rate comparable to the slowest of the component codes.

3. The processing of codes from multiple code categories causes the rate of output processing to be done at a rate comparable to the sum of the rates for the component codes.

4. Increasing the number of targets to be identified decreases the rate of overall, input and output processing and decreases the accuracy of identification. Doubling the number of targets to be identified will double the total time per target required for each target, while the input time will increase approximately 84%, and the output time will increase 10%.

5. The amount of change with changes in the number of targets to be identified is moderated by the particular code categories being identified, i.e. there is a code by number of targets interaction.

6. The presence of co-located, (irrelevant), noise codes from a separate category will affect processing, particularly when a large number of codes are being identified. The particular effect seen will depend on the particular category of codes being identified. However, it appears that very rapidly identified codes will be identified more slowly and more accurately when they are presented with noise codes in the display. The primary locus of the noise codes affects appears to be in input.

7. The impact of response mapping is mostly in output, in that a mapping with more than one code assigned to each response will be output more and more slowly relative to a mapping where there is one code assigned to each response as more and more responses are required. However, there is an impact on input which is dependent on 1) the type of code, 2) the number of codes being identified, and 3) the amount of experience with the task. When an inexperienced performer is attempting to identify a large number of codes and those codes are from multiple code categories, the use of a mapping with one code per response will have slower input than one with multiple codes per response. Examining the input and output times for the different code conditions suggests that when the coding and response mapping are perceived as relatively complex, i.e. the codes being identified are not readily processed, (e.g. the identification of letters as opposed to digits, as argued by Briggs, 1974) and with a single code mapped to each response, more of the translation associated with the response panel appears to take place in output than when the tasked is perceived as simple.

In general, the results of the studies in Chapter 4 & 5 are consistent with the processing model described by Teichner & Williams. If we accept that the translation of codes is an essential aspect of processing, then it would make sense that processing would be affected by the number and particular form of the codes being processed. For instance, given Briggs' (1974) assertion that digit

codes are processed as individual codes on a regular basis in the context of task outside the laboratory while letters are not, it would make sense that digits should be processed more quickly than are letters in a code identification task such as that used in Chapters 1 & 2. Further, Teichner (1977, 1978; Teichner & Williams, 1977) assert that the majority of the translation process occurs during input. Therefore, it would be expected that the largest proportion of time in these code identification tasks should be associated with input which they are for both the type and number of code manipulations, which they are.

The effects of identifying codes from multiple code categories was not predictable based on the Teichner models. That input processing of codes from multiple categories should be comparable to the most slowly identified codes, however, is consistent with the model. It would suggest that a basic processing strategy, i.e. a fixed sequence of stimulus-stimulus translations is set-up in working memory at the start of the task. This sequence is applied to all stimuli regardless of their source. Further, the possibility of there being more efficient stimulus-stimulus translations being available for particular subsets of codes in the display does not affect the overall T_{S-S} sequence. In essence, the codes in the display are processed as if they come from a single category, and the category that determines the initial T_{S-S} sequence is the one which allows for all the codes to be processed. Such an interpretation is consistent with the results seen in output. It was found that the rate of output for identifying codes from multiple categories was, on average, comparable to the sum of the output times required for the codes in each of the component code categories. Thus, there is an output cost for processing the codes with a single, common sequence of stimulus-stimulus translations in that the stimulus-response translation becomes more difficult as the common set of memory codes must be converted to one of two sets of output (response mapping) codes. The output processing of

codes from multiple code categories may therefore require an extra translation stage during output[25].

The effect of noise codes would be expected to be almost entirely in input, based on the Teichner models. It would appear that this is in fact the case. Apparently, the presence of collocated noise codes also causes an decrease in the rate of processing for certain categories of codes which are very rapidly identified. Again, the implication is that a more efficient stimulus-stimulus translation strategy must be abandoned in favor of a more conservative one. This translation strategy results in performance comparable to that seen in more slowly processed independent code categories, in terms of both speed and accuracy. The suggestion, then, is that the effect of an irrelevant (noise) code category is fairly minimal, though it is clear the noise codes are being processed. However, the noise codes receive minimal processing in working memory. In effect, the noise codes receive only the processing necessary to filter them out after having been sent into working memory, perhaps by the activation mechanism in the Teichner model.

There were two subtle, and somewhat problematic, effects found in the presence of noise codes described in Chapter 5 as a function of the response mapping. The first effect was in input where the identification of four letter codes with digit noise codes was performed more slowly late in practice when responding was done on the compound response mapping. If we accept Briggs' (1974) suggestion that letters are processed more slowly due to that lack of subject familiarity in

[25]One conceivable test for this hypothesis would be to use a single code category on the response category, and assess the impact on output time when compared to response mappings which represent both response categories. For instance, presenting a matrix of digits and letters to be identified, where the response panel could be either of those used in these studies, and compare performance to a panel consisting of only digits or only letters. With the single code response mappings, the "1" button would be used to identify either the"1" or "A" codes, the "2" would be considered the correct response for either "B" or "2", etc. If we compare the output times for these two conditions, it should be found that no additional translations are required when the response mapping consists of codes from a single code category, if in fact they are being processed as a single, common code in working memory.

processing them as individual codes, this effect could be accounted for by fatigue, as the processing of a large number of such codes could be considered to be more demanding, and after a substantial period of time performing a task, would be more susceptible to such effects.

The second effect relates to output. In the identification tasks described in Chapter 5 only codes from a single code category were being identified. Therefore, the mapping of the irrelevant codes as separate from, or coincident with, the relevant codes on the response panel was not expected to have an effect on output. Somehow, the response mapping did result in a significant interaction effect with the target-task condition when a large number of targets were being identified (Figures 5-7b, 5-9). The only mechanism which would seem to explain how the compound response mapping could affect output under these conditions attributes the decrement in output to the collocation of irrelevant codes on the response panel. This would imply that some sort of input related to response execution takes place during output, and in the process the presence of irrelevant codes then serves to complicate and slow down the output to the compound response mapping, though these keys are being used to identify targets from a single category. This explanation will be kept in mind as the results from the studies described in Chapters 6 and 7 are discussed.

The studies described in Chapters 6 & 7 were intended to study further how the interrelationship among code categories interacted with each other to affect performance in general and input and output processing in particular. Chapter 6 described a study where the codes were identified from multiple code categories. However, the codes could be assigned to the display with a single code per cell in the display, or multiple codes from different categories could be collocated in the cells on the display (i.e. the separate and compound target-task conditions). The results from this study indicated that:

8. All dependent measures, i.e. total, input and output time per target and accuracy were affected by the collocation of codes from different categories in a single target on the display such that, on a per target basis, the performance was worse with all measures with the collocated codes in a single target.

9. The rate of decrement in performance was affected by the target density, with the compound target-task conditions decrementing faster than the separate target-task conditions. However, an analysis of the rates of change suggested that a more appropriate way of analyzing the data would be on a per code basis rather than a per target basis, i.e. the appropriate conceptual unit of analysis should be in terms of the number of codes which are relevant to performing the task, rather than the number of targets. When analyzed on this basis, it was found that there was a net savings in input for the compound target-task conditions which was attributed to the fewer number of visual fixations with the compound target-task conditions.

10. The use of separate and compound response mappings had significant effects on performance in terms of both input and output processing. Accuracy of code identification was lower when there was a high target density early in practice and the compound response mapping was employed. Generally, accuracy was less stable for the compound response mapping and high target densities throughout the course of the experiment. Overall, the separate response mapping led to slower input of the codes in both target-task conditions. However, there was an interaction with the separate and compound target-task manipulation, in which the rate of input for the separate targets improved much faster than it did with the compound target-task conditions, particularly as larger numbers of targets (codes) were presented to be identified. Output processing was slowed 3.25 times faster as

the number of targets to be identified increased with the compound response mapping than it did with the separate response mapping.

11. On a per target basis, it was found that the input of letter codes with collocated noise (digit, e.g. the compound (letters) target-task condition) codes was faster than the input of collocated redundant codes. However, on a per relevant code basis, it was found the input of the compound (letters) and compound codes were equivalent to each other, and the input of redundant codes was faster overall.

12. The input of redundant codes was done at a rate comparable to the compound target-task conditions at the start of practice, and a rate comparable to the compound (letters) condition at the end of practice, suggesting that the two redundant codes in each redundant target are treated as separate codes early in practice, and a single (composite) code later in practice. The transformation of the redundant codes to a single composite code takes place gradually over practice.

13. The output of redundant codes was performed faster than it was for either the single code, or compound codes conditions, suggesting that the translation of codes from memory to an executable response was less demanding for the redundant target-task conditions.

Again, the results from the studies in Chapters 6 and 7 were generally consistent with the Teichner & Williams processing model. One of the more significant findings from Chapters 6 & 7 was the finding that a more consistent interpretation is possible when tasks are conceptually discussed in terms of the relevant codes, rather than targets per se. As shown by Figures 6-19 and 7-14, the effects from identifying multiple codes from the same target were directly comparable in terms of changes in the rate of processing when discussed on the basis of number of relevant codes.

The different intercepts for these functions were explained by the reduced number of visual dwells necessary to read the codes from the display when two codes were collocated in a single target.

The findings from the redundant target-task conditions were particularly interesting. Again, when considered on a per code basis, they make sense in terms of the Teichner & Williams processing model. With regard to input, each code in the fully redundant targets is processed as a separate entity, and therefore the rate of input resembles that for the compound target-task conditions where each code in the target is relevant but unrelated. However, as experience is gained with the task and the redundant targets in particular, the two redundant codes gradually come to be treated as a single code. Therefore, on a per code basis where the redundant codes are treated as a single composite code, the rate of input seen with the redundant codes late in practice is similar to that of the identification of single relevant code targets. That the transition in the rate of performance with redundant codes over practice is gradual is entirely consistent with the Teichner & Williams conception of T_{S-S}. Teichner & Williams suggest that the primary effect of learning is to cause the translation process to become more efficient, i.e. fewer and fewer translations are necessary with practice. The data, particularly with the redundant target-task conditions used in this study directly supports the assertion.

The results for output time with the redundant target-task conditions are also consistent with the Teichner & Williams conceptualization of output processing. The rate of output processing on a per code basis for the redundant codes was comparable to that for the identification of both single codes and multiple codes from a single target. However, the intercept for the redundant codes was approximately half that for the conditions where the codes being responded to had no relationship. The similar rates of output with increases in the number of responses suggests that, overall, the T_{S-R} for the redundant codes were the same. Thus, though twice as many responses were required for the redundant target-task condition, a single stimulus-response translation was

required for the two redundant codes. The lower intercept for the redundant codes reflects the fact that two responses were being executed for every response selected, and this was done with minimal costs in processing. In sum, these results are consistent with the conceptualization of output consisting primarily of a single T_{S-R}, R-Sel, and R-Ex.

Theoretical Implications of Results - A Revised Processing Model.

While the results obtained in these studies are generally consistent with the suggestions of the Teichner & Krebs (1977) model described above, there are several idiosyncracies relating to output which suggest a modification to the model may be appropriate. Two issues suggest that a modification to the Teichner & Williams model might be appropriate. One of these stems from considering how the model might be made more general to apply to tasks other than those used in WiTS research to date. Specifically, how could the model could be used to describe a task that was less discrete (e.g. one which entails a very complex sequence of responses or even a continuous control task).

In a continuous control task, such as a tracking task, there is difficulty in discriminating inputs from outputs. In effect, the task consists of a continuous series of input and output cycles where the operator performing the task must input the status of the system, how it has changed since the last inputs, interpret how his previous control inputs have affected the system, and then determine and execute appropriate control outputs (e.g. Poulton, 1974). Clearly this is a task which was beyond the original intentions of the Teichner (1977, 1978) and Teichner & Williams (1977) processing models. However, it is desirable that the model be able to describe how such a task be performed.

The second issue relates to the empirical findings in the studies described in Chapters 4 & 5, some of which are difficult to account for with the Teichner & Williams model. These effects took the form of several interactions between several of the target-task conditions, the target density and the particular response mapping being used. Specifically, in Chapter 5 it was found that the presence of noise codes had an effect on output processing, but only when a large number of codes were being identified. It was argued above that this finding could be accounted for by the presence of a secondary input taking place in the course of output. The presence of the irrelevant codes in the output, particularly when those irrelevant codes are collocated on the same response keys as they were in the compound response mappings used in these studies, serves to complicate and slow down the output in the compound response mapping. A primary feature of the revised model is the presence of this secondary input mechanism which provides additional information for output.

Both these issues can be addressed with what will be refereed to as an "Iterative Cascade Model". This model is shown in Figure 8-2. The model is similar to the Teichner & Williams (1977) model except that 1) the stages are not assumed to be strictly serial, and 2) it is assumed that there is a limited input which occurs during output to drive output processing. The stages are said to occur in cascade because, while they do occur in a sequence, the processing in one stage may begin before all processing has been completed in the preceding stage. The relative occurrence of stages in time, however, is thought to be relatively stable. It may be that the time when a succeeding stage begins relative to a preceding stage is not fixed, and may be affected by such factors as general task demands, and experience with the task. However, it is asserted that the relative duration and timing of the stages is relatively stable. Thus, because a succeeding stage may begin while a preceding stage is ongoing, but cannot begin until the preceding stage has begun to output, the stages are said to occur in cascade.

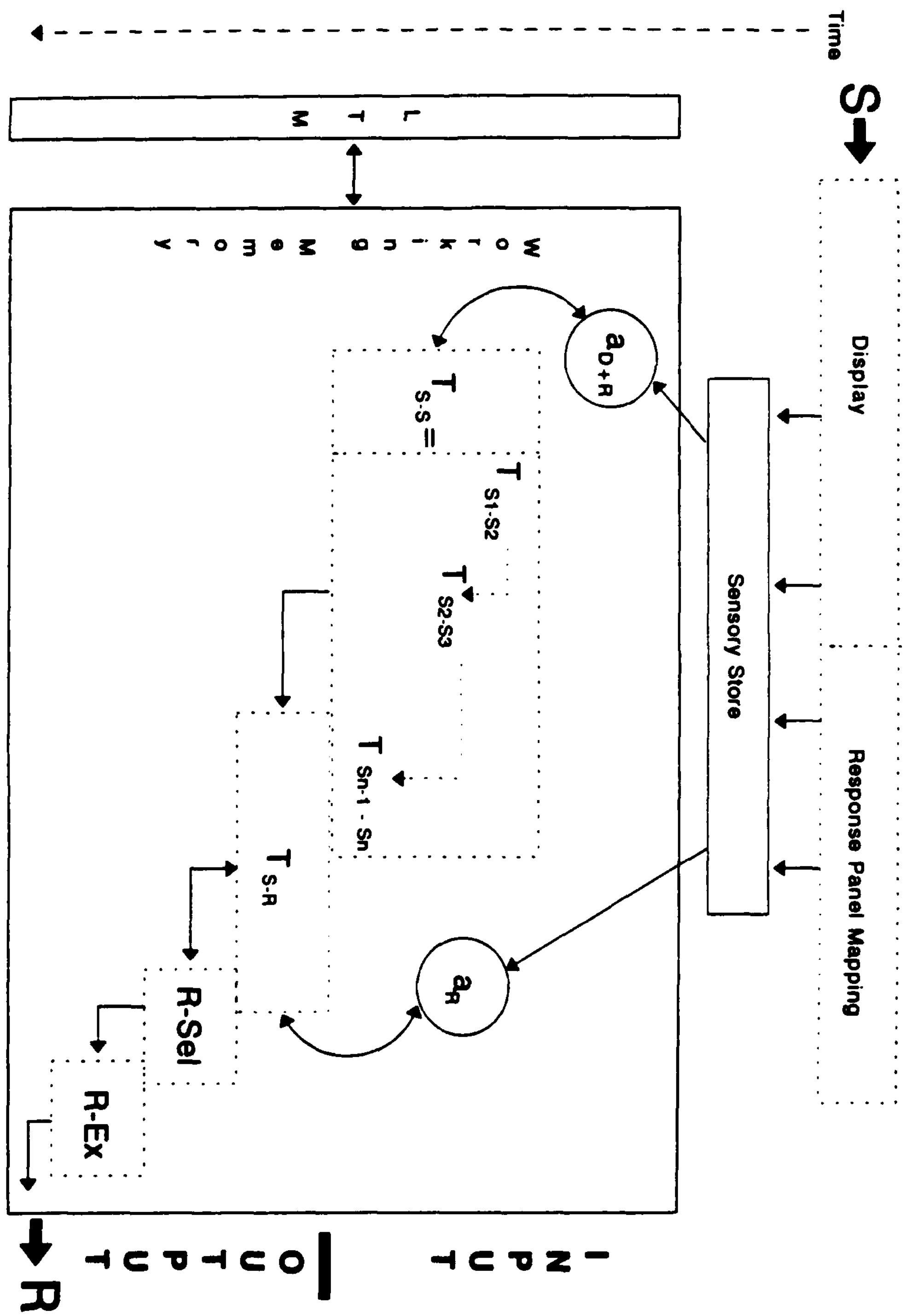


Figure 8-2. Iterative Cascade Processing Model.

The model may be considered iterative for two reasons. First, in discrete tasks, such as those used in this research, information related to the output side of the task occur twice. During the input stage, the information regarding the output is fairly general and is limited only to that information required to determine the appropriate responses. The second input, which occurs at the start of output, is used to obtain information necessary to develop a motor program and control the responses to be made as determined during input processing. Thus, the model is iterative because it involves multiple inputs, each of which serves a different purpose in the course of performing the task. Further, during very complex tasks it may be that not all processing is completed in a single processing cycle. For instance, when the outputs are extremely complex, it may be that a sequence of responses are issued by the subject, and then a pause is seen in responding as additional information is accumulated and processed. Thus, the second reason the model can be considered iterative is because the processing cycles consisting of input and output may be considered to be cyclical. The iterative aspects of the task may be extended to less discrete tasks. For instance, in a continuous control task, a new cycle of input may be begun as the outputs from a previous processing cycle are still being executed.

The cascade model is suggested for a variety of reasons. First, the notion of an iterative cascade of stages has intuitive appeal. It does not seem logical that the functionality of the brain would be organized so that large areas would be idle while each of a series of sequential processes is performed. Therefore a strictly serial model seems in appropriate. Clearly, processing takes time, and the manipulation of different experimental factors has demonstrated that there are distinct patterns to the changes in time required for different factors across a variety of experimental paradigms. Therefore, a strictly parallel model does not seem appropriate either. Further, if a model is to be general, it must be applicable beyond the discrete processing tasks that are so common to the experimental psychology literature. A model of processing should be applicable to continuous control, e.g. tracking tasks. Clearly, such a task requires that there be a continuous

feedback loop where the subject is monitoring his own outputs, and compare them to desired results to changes in the performance of the controlled system. Such performance does not appear as a series of discrete cycles of processing, such as would be demanded by a serial stage model where each cycle took a fixed period of time. The most parsimonious solution to explaining processing across discrete and continuous tasks would appear to be a model of stages that are performed in an iterative cascade.

The proposed model is described in detail as follows:

S - Sensory Input. This consists of all that information in the display and response mapping which affects the performance of the task.

Sensory Store - A very short term sensory memory, (e.g. Sperling, 1960; Teichner, 1977, 1978; Teichner & Williams, 1977).

a_{D+R} - Display & Response Information Accumulator. An accumulator mechanism (e.g. Teichner & Williams, 1977) which detects stimuli in *both the display and response panel mapping* from the sensory store. The mechanism detects information in accordance with the Grice (1968) variable criterion theory. The criterion for what constitutes information is affected in part by the task demands (e.g. instructions to the subject), and in part by experience with the task and factors such as arousal. Only that information perceived as necessary for stimulus-stimulus translation is input into working memory, particularly as the task becomes more demanding. The accumulator may also play a part in setting the basic clock speed, or rate of processing, in working memory.

$T_{S\text{-}S}$ - Stimulus-Stimulus Translation. A series of stimulus-stimulus translations, ala Teichner & Williams (1977). Information which relates to both the information in the stimulus and to certain

limited aspects of the response panel affects the translations that take place. Translations may include:

1) Translation from detected codes to a suitable memory representation.

2) Translation involving sorting of relevant and irrelevant codes (the relevance may in part be determined by the presence and general arrangement of codes on the response panel).

3) Manipulations of the codes as required by task demands. These manipulations may be affected by processing strategy and experience in performing the task. There may be a number of such translations particularly when the task is complex and/or when the task is novel.

4) There is a final Stimulus-Stimulus translation whereby the codes which are to be responded to are stored in working memory.

a_R - Response Mapping Accumulator. A second iteration of information accumulation occurs after the first accumulation has been completed. However, different information is gathered for working memory by this accumulator. The accumulator gathers information regarding the arrangement of responses on the panel rather than the identity of the response, thus the information may be qualitatively different from that gained through the initial accumulation. Again, the accumulator is assumed to work in accordance with variable criterion theory.

$T_{S\text{-}R}$ - Stimulus-Response Translation. As per Teichner & Williams, there is a stimulus-response translation in which the codes to be responded to are translated to executable responses. The responses are generated based on the results of $T_{S\text{-}S}$ and the response mapping information gained through a second input (a_R).

R-Sel - Response Selection. That processing associated with taking the outputs of stimulus-response translation and converting them to a sequence of responses and a motor program.

R-Ex - Response Execution. That processing associated with monitoring and controlling motor movements during execution.

Future Directions.

The intent of this research was to demonstrate the within-task subtractive methodology and a theory of information processing which focused on input and output, and in so doing generate meaningful theoretical, methodological and practical results. It is hoped that the reader agrees that this intent has been met. The question now becomes one of: Where to go from here? This question has already been addressed to a limited degree in the course of each of the studies described in Chapter 4-7, and will now be summarized here in general terms.

One of the primary questions asked in this research was that of the effects of codes. Factors relating to the type and arrangement of codes in both the display and the response panel were manipulated and found to have effects on both input and output processing. Clearly there is a need to continue to assess how the use of different codes and code properties assesses processing. The WiTS methodology, as used in this paper would readily allow the comparison of display icons and pictorial symbology to be addressed, as well as such coding properties as color and shape coding, the effects of manipulating the ordinal properties of codes, etc. The issues of noise and code redundancy have only been touched on in this report. Other manipulations of the presence of noise codes and their relationship to relevant codes are present in the coding literature, and could be

employed within the context of the WiTS methodology. With regard to redundancy, only the case of total redundancy was studied in this report, however redundancy can be seen as a continuum where codes are only partially redundant. Clearly, it could be very worthwhile to study redundancy further than was done in this report.

The issues of codes and coding are closely related to those of display formats. The WiTS methodology as used in this report could be used to assess how different formats, or arrangements of information in a display screen, affect the way that information is input and output. One simple example might be to take the presence of a display grid, which in this study was limited to defining a four by four cell matrix, and comparing performance on comparable tasks with different matrix arrangements, such as when a two by eight cell matrix is used or no matrix is presented at all. Such a manipulation might lead to interesting findings regarding what in a display provides information, and how that information affects different aspects of processing.

Future research, such as that suggested for continuing to study codes and display structure may want to incorporate methodological development as well. For instance, the incorporation of an occulometer in studies of coding and display formatting may allow assessment of how information is input during various stages of processing as a function of other experiment manipulations. Such a development would then allow further theoretical development, and the construction of a more detailed processing model than was possible in this research. In addition, the incorporation of measurements of movement times and response sequence data, which was beyond the scope of the studies described in this report, would also facilitate a more detailed study of processing than was possible here.

Another issue that should be pursued in future research is the role of different processing tasks. Teichner (1977) for instance describes three basic categories of processing tasks: information

conservation, where the amount of information in the output is equal to the amount of information in the input, e.g. the target identification task used in the studies of Chapters 4-7; information reduction, where the amount of information transmitted in output is less than the amount of information input; and information creation, where the amount of information in the responses exceeds the amount of information in the input. It may be interesting to look at manipulations such as those used in these studies in the context of these different kinds of information processing tasks in order to see how the input and output processing is affected by the different kinds of tasks.

Another aspect of tasks the deserves further attention is that of explicit strategy. It should be possible to construct tasks which either force different processing strategies to achieve the same ends, or facilitate different processing strategies that may be manipulated through task instructions. For instance, the ordinal aspects of digit and letter codes could be made relevant to the processing task, and then different arrangements of digits and letters may be employed to force different code sorting strategies in performing the task. Alternatively, different categories could be used in combination with different task instructions. For instance, the compound target-task used in Chapters 6 & 7 could be employed. However, subjects would be instructed to identify one category of targets before the other, or instructed to identify a target from each category in alternation. In effect. these manipulations of task instruction may serve to make the task more or less complex and therefore demanding. Similar effects could be achieved by simply increasing the number of alternative codes, and/or response alternatives. The iterative cascade processing model was explicitly developed to describe how processing might occur in such tasks. It would be very useful to develop variants of the WiTS methodology which could be used to assess input and output processing in such less discrete or even continuous control type tasks.

Clearly the results obtained so far in using the Within-Task Subtractive methodology and an input-output processing model illustrate the potential value of future research using this approach to

studying human information processing. The issues reviewed above at a general level, and those described in detail elsewhere in this report illustrate that there is a great deal of work yet to be done. The WiTS methodology, because it is less restrictive in its assumptions, is uniquely suited as a tool for performing this work.

(This page intentionally left blank.)

CHAPTER 9 - Conclusion

This research set out to address a variety of issues related codes and coding. The research described assessed the validity of a premise common to much human performance research: that the nature of processing not affected by the particular codes used or their arrangement in the display and response panel. A review was made of code and coding research described in the literature, and the findings of this research was discussed in terms of their implications as to how codes in the display, their relationship to each other, and the codes and arrangement of codes in the response mapping might affect processing. The results obtained demonstrated that not only do the particular codes used in an information processing task affect the performance seen in that task as measured by speed and accuracy, but those effects may be subtle and complex.

The processing model, and methodology used to generate the findings was based upon the conception of processing as consisting of two essentially sequential stages, described as input and output. Input processing entails the input of information from a display and encoding it into memory. Output processing was said to involve the use of codes in working memory, translating them to desired responses, and then executing those responses. The model and methodology used, e.g. the Within-Task Subtractive (WiTS) methodology, were discussed in detail and compared to alternative response time partitioning procedures and models. The WiTS methodology was advocated as one with significant applied and theoretical utility because it required minimal, and relatively non-controversial assumptions. Because of these minimal assumptions, the WiTS methodology should be applicable to a wide variety of information processing tasks, including those

more typical of applied settings. Therefore the studies described in this report served to demonstrate the WiTS methodology and its utility in addressing a variety of code and coding issues.

The specific code/coding issues addressed included the relative performance in terms of input and output in an identification task where one of two different categories of codes were employed. The specific codes used were digits and letters, because they are commonly used in the human performance literature, and share a number of similar properties. Despite their similarities, it was found that digits and letters are processed differently in terms of input and output.

The effects of different categories in an identification task were also assessed in the context of a study concerned with the presence of irrelevant, or noise, codes collocated with a relevant code. The codes used were again digits and letters. However, when the letters were the relevant code category the digits served as noise, and when the digits were relevant letters were used as noise codes. Thus, the results of this study served to continue the assessment of the effects of code categories, except that the categories served to differentiate noise and non-noise in the display. The results of this study showed that the presence of noise codes in display targets served to change processing, particularly in terms of input processing. Minimal output effects were found for the presence of noise codes as well, particularly with certain response mappings. The results were interpreted as showing that noise codes do receive some degree of processing. However, the processing given to noise codes was different from that seen for relevant codes.

The third study described in this report involved assessing the effects of codes from multiple code categories (digits and letters) which were either presented in separate targets or with multiple codes collocated in the same target. The data analysis revealed performance differences depending on the code arrangements in both the display and response panel. When the results were analyzed on a per code, as opposed to a per target basis, it was concluded that, in fact, the difference in

processing related purely to the reduced number of visual fixations required when multiple codes were collocated in the same target, rather than a difference in input and output processing per se.

The effects of alternative response mappings were assessed in the first three studies. The mappings used in the studies were chosen to mimic two general schemas found in computer keyboards: a separate response mapping where a single response code is associated with each response key, or a compound response mapping where multiple (i.e. two) codes are mapped to each response key. It would appear that many researchers effectively assume that the response mapping is relevant only to response execution, and not a major factor in the way information is processed. The empirical results in this research, however, indicated that this is not the case. Factors relating to the response side of the task clearly affect not only the response side of the task, but affect the input side of the task as well. Further, the manipulation of factors relating to the output side of the task interacted with experimental manipulations traditionally used in the study of information processing. Therefore, it is asserted that factors relating to the response side of the task can have important effects on how information is processed. Further research is required to better ascertain how the output side of the task affects the input side of the task.

The last study described in this report continued the assessment of how collocated codes from multiple code categories affect processing. Specifically, the impact of collocated redundant codes was compared to that for collocated codes where both codes were relevant but unrelated, and the case where there are two collocated codes, one of which was irrelevant (i.e. noise). The results indicated that the processing of redundant codes changes with practice. Early in practice, each code in the redundant targets is treated as an individual code. As practice continues, the codes come to be treated as a single or composite code. It was found that although the fully redundant codes required a response for each code in the target, the output of redundant codes was faster than that required for relevant but unrelated codes on a per response basis. The results in output were

interpreted as being due to a requirement for fewer stimulus-response translations (T_{S-R}) in output with the fully redundant codes.

The last major concern discussed in this report related to theories of processing and the development of a general processing model which might account for all the phenomena found in the empirical studies related in this report. An iterative cascade model was developed based on the Teichner & Williams (1977) processing model for discrete information processing tasks. The model developed differed from other processing models described in the report in several respects. First, the model noted performance in output processing which suggested that a secondary input occurred during output (at least under certain highly demanding task conditions). This second input was argued to be different from that which took place early in input in terms of its shorter duration, and the input of qualitatively different information. The model may be considered iterative in the respect that there are two distinct inputs which occur at different points in processing. A second major difference from earlier processing models was that the model was described as a series of processing stages which were not strictly serial, i.e. took place in a cascade. The processing in one stage could begin before all information had been output from a preceding stage. Finally, it was suggested that the processing cascade could occur in an iterative manner in order to describe how complex tasks of extended duration could be performed, e.g. with a continuous control task.

It should be evident to the reader of this report that the Within-Task Subtractive methodology is an elegant and powerful tool for the study of human performance and human cognition. It is versatile in that it may be applied to a larger variety of processing tasks, and may be extended to application research fairly readily. A variety of general and specific directions for future research were described throughout this report. It is hoped that the reader is sufficiently impressed with the methodology, and finds the issues brought about by this document intrinsically interesting, such that he or she will be inclined to pursue some of this work in his or her own laboratory.

REFERENCES

Andre, A. D., and Wickens, C. D. (1988). The interaction of spatial and color proximity in aircraft stability information displays. In *Proceedings of the Human Factors Society 32nd Annual Meeting*. Santa Monica, CA: Human Factors Society, 1371-1375.

Ashby, F. G. (1982). Deriving exact predictions from the cascade model. *Psychological Review*, **89**, 599-607.

Atkinson, R. C., and Shiffrin, R. M. (1968). Human Memory: A proposed system and its control processes. In W. K. Spence and J. T. Spence (Eds.), *The Psychology of Learning and Motivation. Volume 2.* New York: Academic Press.

Attneave, F. (1954). Some informational aspects of visual perception. *Psychological Review*, **61**, 183-193.

Biederman, I., and Chechosky, S. F. (1970). Processing redundant information. *Journal of Experimental Psychology*, **83**, 486-490.

Bishu, R. M., Drury, C. G., Czaja, S. J. and Sharit, J. (1989). The effects of grouping and cueing in the performance of location tasks. *Applied Ergonomics*, **20**, 206-212.

Briggs, G. E. (1974). On the predictor variable for choice reaction time. *Memory and Cognition*, **2**, 575-580.

Briggs, G. E. & Blaha, J. (1969). Memory retrieval and central comparison times in information processing. *Journal of Experimental Psychology*, **79**, 395-402.

Briggs, G. E., Peters, G. L. & Fisher, R. F. (1972). On the locus of divided attention effects. *Perception & Psychophysics*, **11**, 315-320.

Briggs, G. E. & Swanson, J. M. (1970). Encoding, decoding and central functions in human information processing. *Journal of Experimental Psychology*, **86**, 296-308.

Briggs, G. E., Thomason, S. C. & Hagman, J. D. (1978). Stimulus classification strategies in an identification task. *Journal of Experimental Psychology: General*, **2**, 159-186.

Broadbent, D. E. (1971) *Decision and Stress*. Academic Press, New York.

Brown, C. M. (1988). *Human-Computer Interface Design Guidelines*. Ablex Publishing Corp., Norwood, NJ.

Cardosi, K. M. (1986). Some determining factors of the alphanumeric category effect. *Perception and Psychophysics*, **40**, 317-330.

Corballis, M. C., and Nagourney, B. A. (1978). Latency to categorize disoriented alphanumeric characters as letters or digits. *Canadian Journal of Psychology*, **32**, 186-188.

Corso, G. M. & Kelley, S. (1983). *Binary Classification and the Subtractive Approach*. Technical Report AFAMRL-TR-83-050, Air Force Aerospace Medical Research Laboratory, Aerospace Medical Division, Air Force Systems Command, Wright-Patterson Air Force Base, OH., September, 1983.

Corso, G. M. & Warren-Leubecker, A. (1982). *Binary Classification: A Comparison of the Additive Factor and Subtractive Method Approaches*. Unpublished paper, Georgia Institute of Technology, School of Psychology, Atlanta, Georgia. As Described in: Corso, G. M. & Kelley, S. (1983). *Binary Classification and the Subtractive Approach*. Technical Report AFAMRL-TR-83-050, Air Force Aerospace Medical Research Laboratory, Aerospace Medical Division, Air Force Systems Command, Wright-Patterson Air Force Base, OH., September, 1983.

Dick, A. O. (1969). Relations between the sensory register and short-term storage in tachistiscopic recognition. *Journal of Experimental Psychology*, **82**, 279-284.

Downing, J. V., and Sanders, M. S. (1987). The effects of panel arrangement and locus of attention on performance. *Human Factors*, **29**, 551-562.

Donders, F. C. (1969). On the speed of mental processes. *Acta Psychologica*, **30**, 412-431. (W. G. Koster's English translation of 1868 German article)

Edwards, W. (1965). Optimal strategies for seeking information: Models for statistics, choice reaction times, and human information processing. *Journal of Mathematical Psychology*, **2**, 312-329.

Egeth, H., Marcus, N. and Bevan, W. (1972). Target-set and response-set interaction: Implications for models of human information processing. *Science*, **176**, 1447-1448.

Ellis, S. H. & Chase, W. G. (1971). Parallel processing in item recognition. *Perception & Psychophysics*, **10**, 379-384.

Eriksen, B. A., and Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a non-search task. *Perception and Psychophysics*, **16**, 143-149.

Eriksen, B. A., Eriksen, C. W., and Hoffman, J. E. (1986). Recognition memory and attentional selection: Serial scanning is not enough. *Journal of Experimental Psychology: Human Perception and Performance*, **12**, 476-483.

Eriksen, C. W., and Lappin, J. S. (1965). Internal perceptual system noise and redundancy in simultaneous inputs in form identification. *Psychonomic Science*, **2**, 351-352.

Estes, W. K. (1972). Interactions of signal and background variables in visual processing. *Perception and Psychophysics*, **12**, 278-286.

Flowers, J. H., and Garner, W. R. (1971). The effect of stimulus element redundancy on speed of discrimination as a function of state and process limitation. *Perception and Psychophysics*, **9**, 158-160.

Fitts, P. M. (1954). The information capacity of the human motor system in controlling the amplitude of movement. *Journal of Experimental Psychology*, **47**, 381-391.

Fitts, P. M. (1966). Cognitive aspects of information processing: III Set for speed versus accuracy. *Journal of Experimental Psychology,* 71, 849-857.

Fitts, P. M., and Biederman, I. (1965). S-R compatibility and information reduction. *Journal of Experimental Psychology,* 57, 408-412.

Fitts, P. M., And Seeger, C. M. (1953). S-R Compatibility: Spatial characteristics of stimulus and response codes. *Journal of Experimental Psychology,* 46, 199-210.

Garner, W. R. (1962). *Uncertainty and Structure as Psychological Concepts.* New York, Wiley.

Grice, G. R. (1968). Stimulus intensity and response evocation. *Psychological Review,* 75, 359-373.

Grice, G. R., Canham, L., and Gwynne, J. W. (1984). Absence of a redundant-signals effect in a reaction time task with divided attention. *Perception and Psychophysics,* 36, 565-570.

Grice, G. R., and Gwynne, J. W. (1987). Dependence of target redundancy effects on noise conditions and number of targets. *Perception and Psychophysics,* 42, 29-36.

Grice, G. R., Nullmeyer, R., and Spiker, V. A. (1977). Application of variable criterion theory to choice reaction time. *Perception and Psychophysics,* 22, 431-449.

Grice, G. R., Nullmeyer, R., and Spiker, V. A. (1982). Human reaction time: Toward a general theory. *Journal of Experimental Psychology: General,* 111, 135-153.

Harris, R. L., Glover, B. J., and Spady, A. A. (1986). *Analytical Techniques of Pilot Scanning Behavior and Their Application.* NASA Technical Paper 2525, NASA Langley Research Center, Hampton, VA.

Hendrikx, A. P. (1986). Compatibility of precuing and of S-R mapping in choice reactions. *Acta Psychologica,* 62, 59-88.

Hick, W. E. (1952). On the rate of gain of information. *Quarterly Journal of Experimental Psychology.* 4, 11-26.

Hodge, M. H. (1959). The influence of irrelevant information upon complex visual discrimination. *Journal of Experimental Psychology,* 57, 1-5.

Holmgreen, J. E., Juola, J. F., and Atkinson, R. C. (1974). Response latency in visual search with redundancy in the visual display. *Perception and Psychophysics,* 16, 123-128.

Hyman, R. (1953). Stimulus information as a determinant of reaction time. *Journal of Experimental Psychology,* 45, 188-196.

Imai, S. and Garner, W. R. (1965). Discriminability and preference for attributes in free and constrained classification. *Journal of Experimental Psychology,* 69, 596-608.

Laheij, W., and Vermeij, M. (1987). Reading versus naming: The effect of target set size on contextual interference and facilitation. *Perception and Psychophysics,* 41, 355-366.

Laming, D. R. J. (1968). *Information Theory of Choice Reaction Times.* London, Academic Press.

Larish, D. D. (1986). Influence of stimulus-response transitions on response programming: Examining the relationship of arm, direction, and extent of movement. *Acta Psychologica*, 61, 53-70.

Luce, R. D. (1986). *Response Times - Their Role in Inferring Elementary Mental Organization.* Oxford University Press, New York.

Marteniuk, R. G. & MacKenzie, C. L. (1980). Information processing in movement organization and execution. In: R. S. Nickerson (ed.) *Attention and Performance VIII.* Hillsdale, N. J.: Erlbaum, 1980, pp. 29-57.

McClelland, J. L. (1979). On the relations of mental processes: An examination of systems of processes in the cascade. *Psychological Review*, 86, 287-330.

Merkel, J. (1885). Die zeitlichen verhälnisse der willensthätigkeit. *Philos. Stud.*, 2, 73-127. As described in: W. E. Hick (1952). On the rate of gain of information. *Quarterly Journal of Experimental Psychology*, 4, 11-26.

Miller, G. A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review*, 63, 81-97.

MIL-STD-1472C. (1983). *Human Engineering Design Criteria for Military Systems, Equipment and Facilities.* U.S. Department of Defense, 2 May 1981, Revised 1983, 1984.

Morin, R. E., Forrin, B, and Archer, W. (1961). Information processing behavior: The role of irrelevant stimulus information. *Journal of Experimental Psychology*, 61, 89-96.

Morrison, J. G. (1987). *The effects of Hue and Contrast on a Binary Classification Task.* Unpublished Master's Thesis: Georgia Institute of Technology, Atlanta, Georgia.

Morrison, J. G. (1988). *Proposal for Empirical Study: Demonstration of Oculometer Capability In Assessing of Pilot's Mental Workload Using Primary Flight Displays.* Working Paper LG8873E2010, LASC-Georgia Company, Marietta, Georgia.

Morrison, J. G., Corso, G.M. & Yuasa, M. (1989). *The Impact of Code Redundancy on Latency in an Identification Task.* Paper presented at 33rd Annual meeting of the Human Factors Society, Denver, Colorado, October 16-20, 1989.

Mudd, S. (1983). *Briggs' Information Processing Model of the Binary Classification Task.* Lawrence Erlbaum Associates, Publishers, Hillsdale, NJ.

Nickerson, R. S. (1973). Can characters be classified as digits or letters or must they be identified first? *Memory and Cognition*, 1, 477-484.

Pachella, R. G. (1974). The interpretation of reaction time in information-processing research. In B. H. Kantowitz (ed.) *Human Information Processing: Tutorials in Performance and Cognition.* Lawrence Erbalm Associates, Publishers, Hillsdale, NJ., 41-82.

Pachella, R. G. & Pew, R. W. (1968). Speed-accuracy tradeoff in reaction time: Effect of discrete criterion times. *Journal of Experimental Psychology*, 76, 19-24.

Pashler, H., and Baylis, G. (1991)[a]. Procedural learning: 1. Locus of practice effects in speeded choice tasks. *Journal of Experimental Psychology: Learning Memory and Cognition*, 17, 20-32.

Pashler, H., and Baylis, G. (1991)[b]. Procedural learning: 2. Intertrial repetition effects in speeded-choice tasks. *Journal of Experimental Psychology: Learning Memory and Cognition*, 17, 33-48.

Poulton, E. C. (1974). *Tracking Skill and Manual Control.* Academic Press, New York.

Proctor, R. W., and Fober, G. W. (1985). Repeated-stimulus superiority and inferiority effects in the identification of letters and digits. *Perception and Psychophysics*, **38**, 125-134.

Proctor, R. W., and Fober, G. W. (1988). A response-selection basis for the mixed-category, repeated-stimulus inferiority effect. *Perception and Psychophysics*, **44**, 182-190.

Rosenbaum, D. A. (1980). Human movement initiation: Specification of arm, direction, and extent. *Journal of Experimental Psychology: General*, **109**, 444-474.

Rudolph, F. M. (1992). *An Evaluation of Contrast versus Numeric Coding, Redundancy, and Density on Input and Output Times.* Unpublished Master's Thesis, Georgia Institute of Technology, Atlanta, Georgia, April, 1992.

Sanders, A. F. (1980). Stage analysis of reaction processes. In G. E. Stelmach, and J. Requin (Eds.) *Tutorials in Motor Behavior.* Amsterdam: North-Holland, 331-354.

Schneider, W., and Fisk, A. D. (1984). Automatic category search and its transfer. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, **10**, 1-15.

Schneider, W., and Shiffrin, R. M. (1977). Controlled and automatic human information processing: I: Detection, search, and attention. *Psychological Review*, **84**, 1-66.

Shannon, C. E. & Weaver, W. (1949). *The mathematical theory of communication*. Urbana, Ill., University of Illinois Press.

Shiffrin, R. M., and Schneider, W. (1977). Controlled and automatic human information processing: II: Perceptual learning, automatic attending, and a general theory. *Psychological Review*, **84**, 127-190.

Smith, E. E. (1968). Choice Reaction Time: An analysis of major theoretical positions. *Psychological Bulletin*, **69**, 77-110.

Shneiderman, B. (1987). *Designing the User Interface: Strategies for effective human-computer interaction.* Reading, MA: Addison-Wesley Publishing Co.

Sperling, G. (1960). The information available in brief visual presentations. *Psychological Monographs*, **74**.

Sperling, G. (1963). A model for visual memory tasks. *Human Factors*, **5**, 19-31.

Sternberg, S. (1966). High speed scanning in human memory. *Science*, **153**, 652-654.

Sternberg, S. (1969a). The discovery of processing stages: Extensions of Donders' method. In W. G. Koster (ed.) Attention and performance II, *Acta Psychologica*, **30**, 276-315.

Sternberg, S. (1969b). Memory Scanning: Memory processes revealed by reaction time experiments. *American Scientist*, **57**, 421-457.

Stone, G. C. (1971). Response latencies in visual search involving redundant or irrelevant information. *Perception and Psychophysics*, **9**, 9-14.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, **18**, 643-662.

Swanson, J. M. & Briggs, G. E. (1969). Information processing as a function of speed versus accuracy. *Journal of Experimental Psychology*, **81**, 223-229.

Teichner, W. H. (1977). *Input, Output and Response Blocking in Immediate Recall*. Technical Report, New Mexico State University, Las Cruces, New Mexico.

Teichner, W. H. (1979). Temporal measurement of input and output processes in short/term memory. *The Journal of General Psychology*, **101**, 279-305.

Teichner, W. H., and Krebs, M. J. (1974). Laws of visual choice reaction time. *Psychological Review*, **81**, 75-98.

Teichner, W. H., and Olson, D. (1972). A preliminary theory of the effects of task and environmental factors on human performance. *Human Factors*, **13**, 295-344.

Teichner, W. H., and Williams, E. (1977). *An Information Processing Theory of Human Performance*. Technical Report, New Mexico State University, Las Cruces, New Mexico.

Tole, J. R., Stephens, A. T., Vivaudou, M., Ephrath, A., and Young, L. R. (1983). *Visual Scanning Behavior and Pilot Workload*. NASA Contractor Report 3717, Massachusetts Institute of Technology, Cambridge, MA. for NASA Langley Research Center, Hampton, VA.

Van Cott, H. P., and Kinkade, R. G. (Eds.) (1972). *Human Engineering Guide to Equipment Design*. U.S. Government Printing Office, Washington, D.C.

Welford, A. T. (1968), *Fundamentals of Skill*. London: Methuen.

Welford, A. T. (Ed.) (1980a). *Reaction Times*. London: Academic Press.

Welford, A. T. (1980b). Choice reaction time: Basic concepts. In A. T. Welford (ed.), *Reaction Times.*, London: Academic Press, 73-128.

Wickens, C. D. (1980). *Engineering Psychology and Human Performance*. Columbus, OH: Charles E. Merrill Publishing Company.

Wickens, C. D., and Andre, A. D. (1990). Proximity compatibility and information display: Effects of color, space, and objectness on information integration. *Human Factors*, **32**, 61-77.

Williams, E. (1977). *Input and Output Processes in the Stroop Phenomenon*. Technical Report NMSU-AFSOR-TR-77-3, New Mexico State University, Las Cruces, New Mexico.

Woodworth, R. S. (1938). *Experimental Psychology*. Henry Holt and Company, New York.

Young, L. R. & Sheena, D. (1975). Survey of eye movement recording methods. *Behavior Research Methods & Instrumentation*, 7, 397-429.

(This page intentionally left blank.)

APPENDIX A - Subject Briefing

- Each subject will be brought into the experiment room and given a test for visual acuity to ensure that they have normal corrected (20/20 or better) vision.

- The subject will then be seated in front of the response panel and CRT. The subject will then be briefed with the following.

"This experiment is being performed to study the effect of various display and response coding combinations on reaction time. During the study you will see a matrix containing (digits, letters, letters and numbers) appear on the display at the start of the trial. Your task is to identify as ACCURATELY AND QUICKLY AS POSSIBLE the (digits, letters, letters and digits) using this response panel (point to panel)".

"Before we start I need to get your consent to participate. Please read this form (Give Subject Consent Form). Let me emphasize that you may withdraw your consent at anytime. I also want to point out that if you would like to know what the results of this research are, let me know at the end of the study and I will send a copy of the write up when it is ready to your P.O. box."

- (When form is completed - continue)

"Now let me explain your task in detail."

"You will be pacing yourself, that is you determine when to start each trial. To do this, hold down the square button at the bottom of the response panel with your *RIGHT INDEX FINGER* (POINT to button and show which finger). Hold this button until you start responding. When you know what items are in the display and are ready to start identifying the items in the display, take your right index finger off the square button and press the appropriately labelled button (with the same finger). Continue pressing buttons until you have identified every item in the display. If the same (digit / letter) appears more than once, press the button as many times as there are (digits / letters). Please use only your right index finger to push the buttons. When you have finished identifying all the items in the display, go back to the square button and the bottom and hold it down until you see the message "Done Timing". If you want to stop for a minute then let up the button when you see that message. (Verbally walk through a trial - point out that the number of items to be identified will vary across trials (2, 4 or 6 items))".

"I should tell you that the display will disappear after a certain amount of time has passed, or when you press the first button - so be sure you know what items are in the display before you make your first response. You also have a limited time to make a response, so again, please respond as accurately and quickly as possible. If you make a mistake, continue to identify targets and finish the trial as best you can. If you need to ask a question, please wait until the end of a trial (when you see the done timing message), then release the square button and ask me then. If something goes wrong, tell me immediately. The experiment should last about 45 minutes."

"Any Questions?"

SUBJECT DEBRIEF

"I mentioned at the start of the study that I am examining how various information codes affect performance. Performance is being measured in terms of Reaction time and response accuracy. The task you've been performing was designed so that I could partition the reaction time from each trial (break it up) into two components - Input time and output time. Input time conceptually is the time to take in information from the display and store it in memory. Output time is the time required to take information from memory and execute a response."

"You were in one of 13 different conditions. The conditions change in terms of : the codes being used and how they are arranged, how the codes are arranged on the response panel, and the instructions I give the subjects. My primary interest is in seeing how these manipulations affect input time and output time. I am particularly interested in seeing how changing the response panel, for instance assigning multiple codes to the same keys, affects input times and output time. If you think about it, you would expect that changing the response panel would only affect output time, and this is what most people assume. However, no one has ever tested it. What I am trying to test is if this is in fact an appropriate assumption, or if changing the response side of the task in fact also changes the input side of the task."

"This question, Does the response side of a task affect the processing of the input side of the task is important for a variety of reasons. First, theoretical models of how people process information generally assume that processing consists of a sequence of stages, and there is no provision for the output (response) side of performance to affect the input side. Second there are practical implications in designing person-machine interfaces, e.g. multifunction keyboards. If putting a lot functions on a common control changes the way people think about doing some task, that would suggest that we need to better understand how processing is changed by this multi-function type of control."

"Questions?"

"Do you want me to send you a summary of the results?" (Mention time frame for finishing the study).

- Thank subject for participation.

SUBJECT CONSENT FORM

Experiment

NUMBER: Y-10

TITLE: The Effects of Response Codes on Information Processing in an Identification Task.

Experimenter: Jeffrey G. Morrison **Supervisor:** Dr. Gregory M. Corso

By signing this form you are consenting to participate in this experiment. In return for your participation you will receive class credit as per Georgia Tech. School of Psychology policy. You have the right to withdraw from the experiment at any time and will receive credit for the time you have participated.

____________________________ ________________

Signature Date

____________________________ ________________

Name (Printed) Tech. Box Number

____________________________ ________________

Instructor to receive credit Class Number & Section

(This page intentionally left blank.)

APPENDIX B - Means for Main Effects

Chapter 4 - Digits, Letters, Separate. [26]

Effect:	% CORRECT:	TOTAL TIME:	INPUT TIME:	OUTPUT TIME:
Target-Task:				
Digits	96.5	2687	1636	375
Letters	98.1	3379	1756	396
Separate	97.3	3647	1951	471
Response Mapping:				
Separate	--	--	--	--
Compound	--	--	--	--
Targets:				
2	98.3	2198	1253	401
3	97.8	3143	1766	412
4	95.9	3757	2323	429

[26] No data in a cell indicates that there was no significant difference found for the effect.

APPENDIX B - Means for Significant Main Effects

Effect:	% CORRECT:	TOTAL TIME:	INPUT TIME:	OUTPUT TIME:
Blocks:				
1	--	3519	1910	531
2	--	3094	1768	439
3	--	3040	1746	428
4	--	2990	1739	412
5	--	2947	1758	395
6	--	2983	1759	402
7	--	2962	1774	392
8	--	2902	1758	380
9	--	2967	1805	382
10	--	2934	1791	379

APPENDIX B - Means for Significant Main Effects

Chapter 5 - Digits, Compound (Digits), Letters, Compound (Letters). [27]

Effect:	% CORRECT:	TOTAL TIME:	INPUT TIME:	OUTPUT TIME:
Target-Task:				
Digits	--	2767	1636	375
Digits (Compound)	--	2956	1756	396
Letters	--	3379	1951	471
Letters (Compound)	--	3357	2053	430
Response Mapping:				
Separate	--	--	--	--
Compound	--	--	--	--
Targets:				
2	98.4	2099	1291	404
3	97.7	3076	1823	417
4	96.0	4169	2432	434

[27] No data in a cell indicates that there was no significant difference found for the effect.

APPENDIX B - Means for Significant Main Effects

Effect:	% CORRECT:	TOTAL TIME:	INPUT TIME:	OUTPUT TIME:
Blocks:				
1	--	3595	1983	535
2	--	3158	1832	440
3	--	3141	1828	436
4	--	3063	1815	413
5	--	3019	1817	399
6	--	3059	1835	403
7	--	3041	1828	403
8	--	2987	1824	386
9	--	3028	1866	383
10	--	3017	1859	384

APPENDIX B - Means for Significant Main Effects

Chapter 6 - Separate, Compound. [28]

Effect:	% CORRECT:	TOTAL TIME:	INPUT TIME:	OUTPUT TIME:
Target-Task:				
Separate	96.0	3645	1939	--
Compound	82.6	7479	3650	--
Response Mapping:				
Separate	--	--	3021	--
Compound	--	--	2569	--
Targets:				
2	97.4	3387	1660	560
3	91.6	5468	2691	604
4	78.8	7831	4034	623

[28] No data in a cell indicates that there was no significant difference found for the effect.

APPENDIX B - Means for Significant Main Effects

Effect:	% CORRECT:	TOTAL TIME:	INPUT TIME:	OUTPUT TIME:
Blocks:				
1	--	5808	2785	718
2	--	5363	2699	625
3	--	5089	2583	590
4	--	4566	2570	585
5	--	5032	2588	577
6	--	4984	2576	573
7	--	5073	2611	582
8	--	5095	2661	581
9	--	5029	2620	569
10	--	5013	2665	558

APPENDIX B - Means for Significant Main Effects

Chapter 7 - Compound (Letters), Compound, Redundant.[29]

Effect:	% CORRECT:	TOTAL TIME:	INPUT TIME:	OUTPUT TIME:
Target-Task:				
Letters (Compound)	97.9	3515	2123	460
Separate	83.9	6867	3230	600
Redundant	94.0	4956	2864	341
Targets:				
2	98.7	3129	1672	438
3	93.6	5008	2638	472
4	83.5	7200	3908	491

[29] No data in a cell indicates that there was no significant difference found for the effect.

APPENDIX B - Means for Significant Main Effects

Effect:	% CORRECT:	TOTAL TIME:	INPUT TIME:	OUTPUT TIME:
Blocks:				
1	--	5489	3021	577
2	--	5048	2918	491
3	--	4852	2695	497
4	--	4598	2606	461
5	--	4378	2451	448
6	--	4468	2492	450
7	--	4355	2390	464
8	--	4406	2499	441
9	--	4274	2439	428
10	--	4243	2478	414

APPENDIX C - Curriculum Vitae

CURRICULUM VITAE
20 September 1992

Name: Jeffrey G. Morrison **S.S. #:** 044-50-1548

Address:

Home: 301 Heights Lane Apt. 14F
Feasterville, PA. 19053
Phone: 215-322-1975

Work: Naval Air Warfare Center
Aircraft Division
Code 6021
Warminster, PA. 18974-5000
Phone: 215-441-1443

Birth:

Date: July 18, 1961 Place: Danbury, CT., U.S.A.

Education:

Undergraduate:
University of Connecticut
Storrs, Connecticut 06268
Dates Attended: September 1979 - May 1983.
Bachelor of Arts - Awarded May, 1983.
Major: Psychology.
Minors: Sociology, Anthropology.

Graduate:
Georgia Institute of Technology
Atlanta, Georgia 30332
Dates Attended: September 1984 - Present.
Doctorate of Philosophy - December, 1992
Master's of Science - September, 1987.
Major: Psychology.
Program: Engineering Psychology.
Minor: Industrial and Systems Engineering.
Other Activities: Served as co-chair on School of Psychology Student-Faculty committee 1985-1986.

Skills and Areas of Interest:

Professional Interests: Person-machine interaction, human performance and cognition, visual displays, visual search, human-computer interfaces, voice recognition technology and its applications, automation and decision aiding.

Computer Related Skills: Fluent in the BASIC, and Fortran computer languages. I am familiar with C++ as well as the CSS/Statistica, SPSS/PC+, and BMDP statistical packages. I have worked extensively with Apple II's, MS-DOS based Personal Computers, Texas Instruments Professional Computers, and TRS-80 micro computer systems and their operating systems. Has worked with the C.D.C. Cyber 865 super-computer system and has had exposure to the VAX and IBM 4386 super-computers using VMS

operating systems and various UNIX based operating systems. Extensive experience in computer interfacing protocols and the application of personal computers to laboratory experiments.

Hobbies: Interests in mechanics, automobile/motorcycle repair, wood working, electronics, and photography.

Professional Affiliations:

Human Factors Society, 1985-1990, Student member, 1990-Present, Full member.
Society for Information Display, 1985-1990, Student member. Sigma Xi, 1988-Present.
American Psychological Society, 1989-Present, Student member.

Employment:

February, 1990 - Present:

Naval Air Warfare Center - Aircraft Division
P. O. Box 5152, Code 6021
Warminster, PA. 18974-0591

Engineering Psychologist. Duties include project management, design and conducting of research studies examining human performance issues with adaptive automation, the development of a fixed-base medium fidelity simulator, and the development and publishing of adaptive automation principles and guidelines.

Supervisors: LCDR John Schmidt, Ph.D.; LCDR John Deaton, Ph.D.; Michael J. Barnes

June, 1988 - January, 1990:

CDI Corporation - Southeast.
2613 Perimeter Center East, N.E.
Atlanta, GA. 30346

Contract Human Factors Engineer. Worked at Lockheed Aircraft Systems Corporation. Duties included design and conducting of studies in support of Autonomous Landing System contract, development of software to run physiological measurement systems (heart rate and occulometer).

Supervisor: George A. Sexton.

March, 1988 - May, 1988:

Georgia Institute of Technology
School of Psychology
Atlanta, GA. 30332

Research Assistant. Duties included laboratory set-up, design and analysis of research studies. Projects included aircraft camouflage assessment, design and construction of automated system for data collection in a multiple subject signal detection / reaction time task.

Supervisors: Dr. Gregory M. Corso, Ph.D.; and Dr. M. Carr Payne, Ph.D.

October, 1985 - December, 1987:

Lockheed Georgia Company
Dept. 73-E2, Zone 0685
86 South Cobb Drive
Marietta, GA. 30063

APPENDIX C - Curriculum Vitae

Human Factors Intern/Consultant. Duties included performing human factors assessment of Autonomous Landing System contract, development of software and methodology to use physiological measurement systems onboard aircraft and simulators (heart rate and oculometer).

Supervisor: George A. Sexton, William R. Paden.

March, 1988 - May, 1988:

Georgia Institute of Technology
School of Psychology
Atlanta, GA. 30332

Research Assistant. Duties included development of computer base, millisecond timing system for use in camoflauge assessment study and development of user's manual for system.

Supervisors: George A. Sexton, Teresa L. Mann

October, 1985 - February, 1988:

Lockheed Georgia Company
Dept. 73-E2, Zone 0685
86 South Cobb Drive
Marietta, GA. 30063

Human Factors Intern/Consultant. Duties included theoretical analysis of human factors imlications of artificial intelligence technology, the design and conducting of studies assessing CDU format design strategies, the assessment of voice recognition systems for cockpit applications, Development of a Variable Perspective Display concept for use in tactical aircraft, and the development of a Format Assessment Tool validation study. Also served as liaison between Georgia Tech. School of Psychology, and Lockheed.

Supervisors: Dr. Michael A. Companion, Teresa L. Mann, William Paden and George Sexton.

September, 1984 - June, 1985:

Georgia Institute of Technology
School of Psychology
Atlanta, Georgia 30332

Graduate Teaching Assistant. Duties included supervising classes, generating and grading exams, and organization of GAT laboratory, preliminary repairs to a General Aviation Trainer/simulator, and computer interfacing.

Supervisors: Dr. Charles V. Riche, Dr. Michael C. York, and Dr. Gregory M. Corso.

September, 1983 - January, 1983:

Northeast Utilities
New Milford, CT. 06776

Worked as temporary Head-gate Operator at a hydro-electric power generating plant. Duties included monitoring water supply to plant, and assisting in automation - retrofit of headgate facility.

Supervisor: Stan Percy.

APPENDIX C - Curriculum Vitae

Refereed Publications:

Gluckman, J. P., Morrison, J. G. and Deaton, J. E. (1991). Complex task performance as a basis for developing cognitive engineering guidelines in adaptive automation. In: *Proceedings 1991 Human Factors Society 35th Annual meeting*, San Francisco, CA., pp. 116-120.

Morrison, J. G., Gluckman, J. P. and Deaton, J. E. (1991). Human performance in complex task environments: A basis for the application of adaptive automation. In: *Proceedings of the Sixth International Symposium on Aviation Psychology, April 29 - May 2, 1991*, The Department of Aviation, The Aviation Psychology Laboratory, The Ohio State University, Columbus, Ohio, pp. 96-101.

Moody, L. E., Mann, T. L., & Morrison, J. G. (1987) *How Background Noise Similarity Affects Human Signal Recognition and Response Using either Voice or Manual Input.*

Mann, T. L., & Morrison, J. G. (1986) Effects of Display Density and Format Type On Control Display Unit Format Design. *I.E.E.E./A.I.A.A. 7th Digital Avionics Systems Conference, Fort Worth, Texas, October 13-16., 1986.* 330-337.

Reports:

Morrison, J.G., Gluckman, J.P., & Deaton, J.E. (1990). *Adaptive functional allocation for intelligent cockpits: Cockpit Automation Study 1: Baseline study* (Technical Report NADC-91028-60). Naval Air Development Center.

Parasuraman, R., Bahri, T., Deaton, J. E., Morrison, J. G., & Barnes, M. (1990). *Theory and design of adaptive automation in aviation systems.* NADC (6021), Warminster, PA.

Morrison, J. G. (1989) *Operation Principles and Hardware-Software Description for the Techmar LabMaster and LabTender Interface Cards as used at the Georgia Tech Engineering Psychology Laboratory.* Georgia Tech, School of Psychology working paper, 16 January, 1989.

Morrison, J. G. (1988) *Proposal for Empirical Study: Demonstration of Oculometer Capability In Assessing of Pilot's Mental Workload Using Primary Flight Displays.* Working Paper LG8873E2010, LASC-Georgia Company, Marietta, Georgia.

Morrison, J. G. (1988) *User's Guide for the Human Factors Physiological Measurement System.* Engineering Report LG88ER0172, LASC-Georgia Company, Marietta, Georgia.

Morrison, J. G. (1988) *Tutorial for the ASL Series 300 Eye View Monitor as Configured at LASC-Georgia.* Engineering Report LG88ER0170, LASC-Georgia Company, Marietta, Georgia.

Morrison, J. G. (1988) *Proposal For Human Factors Assessment of the HTTB HUD-FLIR System.* Engineering Report LG88ER0168, LASC-Georgia Company, Marietta, Georgia.

Corso, G. M. and Morrison, J. G. (1988) *F-16 Camouflage Development Study: Final Report Addendum.* (Proprietary) School of Psychology, Georgia Institute of Technology, Atlanta, GA. May 31, 1988.

APPENDIX C - Curriculum Vitae

Petrucci, R. J., Sexton, G. A. and Morrison, J. G. (1987) *Comparison of Indicated Airspeed, Altitude, and Vertical Velocity Symbology on Electronic Displays*. Engineering report LG87ER0187, Lockheed-Georgia Company, Marietta, Georgia.

Morrison, J. G. & Martin, O. E. (1987) *The Variable Perspective Display Concept: Theoretical Considerations, Problem Definition, and a Proposal for Empirical Study*. Working paper LG87WP7223-012 (Proprietary) Lockheed-Georgia Company, Marietta, Georgia.

Morrison, J. G. & Companion, M. A. (1985) *Human Factors and Artificial Intelligence: A Literature Review*. Engineering report LG85ER0210, Lockheed-Georgia Company, Marietta, Georgia.

Presentations:

Gluckman, J. P., Morrison, J. G., & Deaton, J. E. (1991). Complex Task Performance as a Basis for Developing Cognitive Engineering Guidelines in Adaptive Automation. *Proceedings 1991 Human Factors Society Annual Meeting*, San Francisco, CA.

Morrison, J. G., Gluckman, J. P., & Deaton, J. E. (1991). Human Performance in Complex Task Environments: A basis for the application of adaptive automation. *Proceedings 6th International Aviation Psychology Symposium, April 29 - May 2, 1991, Columbus, Ohio.*

Morrison, J. G., Corso, G. M., & Yuasa (1989). *The Impact of Code Redundancy on Latency in a Target Identification Task*. Poster presented at: Human Factors Society 33rd Annual Meeting, Radison Hotel Denver, Denver Colorado, October 16-20, 1989.

Mann, T. L., & Morrison, J. G. (1986). *Effects of Display Density and Format Type On Control Display Unit Format Design*. I.E.E.E./A.I.A.A. 7th Digital Avionics Systems Conference, Fort Worth, Texas, October 13-16, 1986, 330-337.

Rose, P., Morrison, J., & Lassiter, D. (1987) *Magnitude of the Orbison Illusion With Moving Targets*. **Presented:** SEPA 1987 Annual Meeting, March, Atlanta, GA.

Work In Progress:

Morrison, J. G. and Corso, G. M. The effects of hue and contrast on Binary classification. (Under revision)

Gluckman, J., Morrison, J., Deaton, J. & Hitchcock, T. (In preparation). *The effects of Adaptive Automation on performance in a complex, multi-modal task environment. Experiment 1: Adaptively Automating tasks that change level of difficulty.*

Gluckman, J., Morrison, J., Deaton, J. & Hitchcock, T. (In preparation). *The effects of Adaptive Automation on performance in a complex, multi-modal task environment. Experiment 2: Adaptively automating tasks that do not change level of difficulty.*

References: Available upon request.

DISTRIBUTION LIST
Report No. NAWCADWAR-92088-60

No. of Copies

Christopher Whaley Georgia Institute of Technology School of Psychology Skiles Building Atlanta, Georgia 30332	1
Defense Technical Information Center ATTN: DTIC-FDAB Cameron Station BG5 Alexandria, VA 22304-6145	2
Center for Naval Analysis 4401 Fort Avenue P.O. Box 16268 Alexandria, VA 22302-0268	1
1299th Physiological Training Flight Malcolm Grow USAF Medical Center Andrews AFB, Washington, DC 20331-5300	1
NAVAL AIR WARFARE CENTER AIRCRAFT DIVISION WARMINSTER P.O. Box 5152 Warminster, PA 18974-0591 (2 for Code 0471) (15 for Code 6021; J. Morrison)	17

DISTRIBUTION LIST
Report No. NAWCADWAR-92088-60

	No. of Copies
Dr. Gregory M. Corso Georgia Institute of Technology School of Psychology Skiles Building Atlanta Georgia 30332	6
Dr. Michael J. Kelley Georgia Tech Research Institute Georgia Institute of Technology Atlanta, Geogrria 30332	1
Michael J. Barnes ARI Field Unit PERI-FA Ft. Huachuca, Arizona 85613	1
CDR John E. Deaton 297 Saxony Court Winter Springs, Florida 32708	1
Dr. Joel S. Warm University of Cincinnati School of Psychology Cincinnati, Ohio 45221	1
Dr. Raja Parasuraman The Catholic University of America Department of Psychology Washington, DC 20064	1
Frederick M. Rudolph 293 Hamilton Trace Marietta, Georgia 30068	1
Kevin Hodge 300 Home Park Ave. Apt. 701 Atlanta, Georgia 30318	1